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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)

MAR 78 M I VITENBERG

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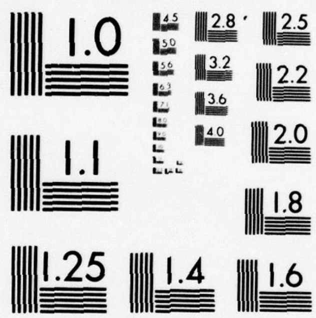

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FOREIGN TECHNOLOGY DIVISION

CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMATION AND COMMUNICATION

by

M. I. Vitenberg

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UNEDITED MACHINE TRANSLATION

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

Page 2.

The book is dedicated to the questions of theory and calculation of the electromagnetic relays of direct current for radio-electronic equipment for automation and equipment for communication/connection.

Are examined physical processes of the occurring in the work electromagnetic relay, are presented the analytical and graphoanalytical methods of the calculation of these relays, are described constructions and are given experimental materials for the fundamental types of relay.

The book can serve as textbook for the students of electrical VUZ [- Institute of Higher Education] and departments and as management/manual for engineers and technicians, working in the range of calculation, construction and application/uses of electromagnetic relays and mechanisms.

Page 3.

PREFACE.

Electromagnetic relays are one of the most important cell/elements of radio-electronic equipment. They widely are applied in many contemporary systems of automation, telemechanics and electric coupling, and also in computers.

In recent years are reached the large successes in construction and production of the diverse types of relay, but for the further improvement of constructions and expansion of production and application/use of instruments and means of automation and computer technology, it is necessary to enforce work in the range of theory and designs of electromagnetic mechanisms.

Are extremely insufficiently developed the questions of the calculation of magnetic, electrical and design parameters miniature/small relays both static and especially dynamic. Are very little studied the problems of wear, erosion, of contact resistance and reliability of weak-current contacts, and also the effect of climatic and mechanical effects on the work of relay.

The difficulties of calculation are determined by the complexity of composition and by the impossibility of the exact solution of the nonlinear equations by which are described the processes occurring in electromagnetic relays.

The nonlinearity of equations is explained by the need the combined account of the numerous factors: the nonlinearity of magnetization curve; the nonuniformity of magnetic flux distribution in air gap and in magnetic circuit; the inconstancy of the effort/forces, which counteract to the motion of armature; eddy-currents effect, hysteresis and reactive emf, induced in the winding of relay during the motion of armature, etc.

On the strength the above the general analytical methods of the calculation of electromagnetic relays are by so complex and bulky that in the majority of cases the calculation cannot be made with the necessary accuracy without the application/use of the auxiliary experimentally determined coefficients and curve/graphs. Therefore in the proposed book considerable attention is devoted to the grapho-analytic (engineering) methods of calculation and to

the empirical formulas, which have largely original character.

Page 4.

The first edition of this book was written on the base of textbook on the course of relay ("Calculation of telephone and code relays", GEI, 1947), which over a number of years was read by author in the Leningrad Electrical institute of the communication/connection in the name of Prof. M. A. Bonch-Bruyevich. The second, reworked and enlarged edition appeared in 1961.

In the proposed third publication are reworked and supplemented in comparison with the second edition the first, fourth, ninth, thirteenth, fifteenth, sixteenth, seventeenth, eighteenth and twenty first of chapter and are introduced new in the content twelve chapter and new §§ 1-25, 4-13, 13-5, 13-6, 13-7, 13-8, 15-3 and 17-3. Additions are made because of the exception/elimination of the calculation of the relay of alternating current, semiconductor rectifiers, rectifying and thermoelectric relays.

In this edition are examined new materials on the

reliability of relay, are given new more precise formulas for the calculation of the attracting force and determination of the optimum size/dimensions of magnetic circuit, are given the new simplified formulas for the calculation of the temperature of the overheating of the winding of relay and are refined some theoretical conclusions. Is examined the effect of climatic and mechanical effects on the work of relay, is presented brief information on tuned-reed relay and are supplemented materials on polarized, magnitoelectric, uvular and mercury switch, and also contacts and spark extinguishing.

Author expresses appreciation to T. K. Shtremberg for the given materials on reliability, the effect of climatic and mechanical effects, on the investigation of the polarized and magnitoelectric relays, spark extinguishing, and contacts, Cand. of tech. sciences V. V. Vishniovskiy and L. A. Dobroserdov for the execution of a series of experimental works, and also to the reviewer of Cand. of tech. sciences V. Z. Royzen for a series of valuable observations.

Author will be grateful to the readers whom will consider possible to send their observations and wishes to: **Leningrad, D-41, Marsovo pole,** d. 1, Leningrad division of **publishing house "Energy".**

Author.

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INTRODUCTION.

V-1. Determination and classification of relay.

The instruments, which realize in equipment/devices of automation abrupt control of the parameters of secondary process under the action of changes within certain limits of the value of primary process, are called of relay.

Relays are one of the fundamental elements of many systems of automation, telemechanics and electrical communication. They make it possible to carry out necessary interaction and required sequence in the operation of the individual parts of the systems (instruments) of automation and telemechanics.

The dependence between secondary y and primary x the parameters is called control characteristic of relay (Fig. V-1). With an increase in parameter x from zero up to value $x_{сраб}$ the value of the parameter $y_{мин}$ does not change, moreover value $y_{мин}$ for the most part is equal to zero. At that torque/moment when parameter x reaches value $x_{сраб}$,

parameter y changes with jump from value $y_{мин}$ to value $y_{макс}$. (Time of a change in parameter y is determined by transit time). With a further increase in parameter x up to value $x_{раб}$ the value of parameter y remains constant/invariable.

During a decrease in parameter x down to the value, equal to $x_{отп}$, the value of parameter y also does not change and only at value x, equal to $x_{отп}$, parameter y abruptly decreases to $y_{мин}$.

Value $x = x_{сраб}$ is called the parameter of the function of relay, a $x = x_{отп}$ - by the parameter of the release/tempering of relay.

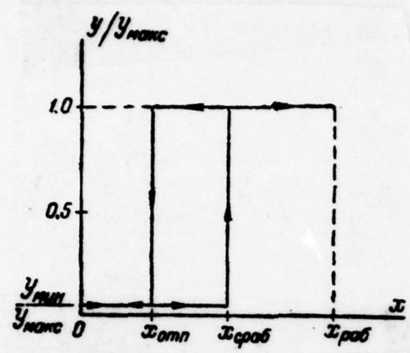

Fig. V-1. Control characteristic of relay.

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Relation $x_{отп}$ to $x_{сраб}$ is called the relay reset coefficient $k_в = \frac{x_{отп}}{x_{сраб}}$, while relation $x_{раб}$ to $x_{сраб}$ - by a coefficient of reserve (from the governing parameter x) $K_1 = \frac{x_{раб}}{x_{сраб}}$ ← [1-1].

To the input parameter $x_{сраб}$ corresponds the power of function or the driving power $P_{ср}$, which must be conducted to receptor for bringing into action (functions) of relay. The power, repeatedly switched by the actuating element of relay, is called the controlled power $P_у$.

The ratio of the controlled power to the power of

function is called the control ratio of relay $k_y = \frac{P_y}{P_{cp}}$.

Depending on the physical nature of the phenomena for which the relay is intended to react, relay are divided on: a) electrical, b) thermal, c) mechanical, d) magnetic, e) optical, f) acoustic, g) liquid and gas, etc.

Is swept the classification of all forms of relay it is given in B. S. Sotskova's book [1-2]; here is given the incomplete classification of mainly electrical relays.

According to the principle of equipment/device of receptors, electrical relays are divided into: a) electromagnetic (neutral), b) (electromagnetic) polarized, c) magnitoelectric, d) electrodynamic, e) induction, f) electrostatic, g) electronic and ionic, h) rectifying, i) semiconductor and others. Resonance, piezoelectric and magnetostrictive relays are related to mechanical relay; composite - to thermal and photoelectric - to optical.

According to the operating principle of actuating elements electrical relays divide into the contact and noncontact. Noncontact relays affect the controlled circuit by sharp (abrupt) changing the parameters (inductance,

capacitance/capacity, etc.) of the actuating element, connected in the controlled circuit; to noncontact are related magnetic, electronic, ionic and other relays.

Depending on the kind of the control current of relay, they are divided into the relay of direct and alternating current.

Depending on the physical quantity from which the relay must wear/operate, they are divided on current relay, voltage, power, resistor/resistance, frequency, time, etc.

In the amount of the required power during the function of the relay are possible to divide into highly sensitive (to 10 mW), sensitive (to 0.1 W) and normal (more than 0.1 W).

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Depending on the amount of the switched power, distinguish: a) the relay for the commutation of the circuits of small power (to 60 W of direct current or to 120 volt-amperes of alternating current by frequency 50-1000 Hz); b) of relay for the commutation of the circuits of

average power (to 150 W of direct current or 500 volt-amperes of alternating current); c) of relay for the commutation of the circuits of increased power (more than 150 W of direct current or 500 volt-amperes of alternating current) and of d) contactors (more than 500 W).

On time of the action of relay it is possible to divide on: a) ultra-high-speed (having triggering times and release/tempering to 5 ms), b) high speed (to 50 ms), c) normal (to 150 ms), d) those who were retarded (to 1 s) and e) the time relay (more than 1 s).

Depending on the designation/purpose of relay, are divided on: a) the relay of radio-electronic automation, b) with the relay of electrical communication, c) the relay of control of electric drives, d) the relay of the protection of power systems, e) the relay of automatic block system, etc.

Depending on the made functions of relay, can be divided on: a) commutation, b) amplifier and c) the controls or measuring [1-3].

To commutation are related the relays, which realize

interactions and communication/connections in relay circuits. Commutation relays most frequently are applied in the circuits of automation, telemechanics, signaling and electrical communication.

Amplifier relays are intended for amplifying of input electrical signal and control of the output electrical circuit of large power.

Control (or measuring) relays are utilized for the checking (or measurement) of the assigned magnitude of electric current or voltage.

Each form of electrical relay is characterized by the specific values of the controlled and driving power, control ratio and time. The exemplary/approximate limits of these values for the different forms of relay are given in Table V-1.

Table V-1. Exemplary/approximate power coefficients of function, controlled power, control ratios and triggering time of the different forms of electromagnetic relays.

(1) Вид реле	(2) Мощность срабатывания P_{cp}, *вт*	(3) Управляемая мощность P_{y}, *вт*	(4) Коэффициент управления k_{y}.	(5) Время срабатывания t_{cp}, *сек*
Электромагнитные (6)	$10^{-3} \div 10^{2}$	$10^{-1} \div 10^{4}$	$10^{2} \div 10^{3}$	$2 \cdot 10^{-3} \div 2 \cdot 10^{-1}$
Поляризованные (7)	$5 \cdot 10^{-6} \div 5 \cdot 10^{-1}$	$1 \div 20$	$10^{8} \div 10^{5}$	$\cdot 10^{-4} \div 2 \cdot 10^{-2}$
Магнитоэлектрические (8)	$10^{-10} \div 10^{-4}$	$0,1 \div 2$	$10^{4} \div 10^{8}$	$10^{-2} \div 5 \cdot 10^{-1}$
Индукционные . (9)	$10^{-2} \div 10^{2}$	$10^{-1} \div 10^{3}$	$10^{2} \div 10^{4}$	$10^{-3} \div 10^{-1}$
Электронные . . (10)	$10^{-12} \div 10^{-6}$	$10^{-3} \div 10^{2}$	$10^{5} \div 10^{9}$	$10^{-8} \div 10^{-7}$
Ионные . . . . . . (11)	$10^{-4} \div 10^{-3}$	$10^{2} \div 10^{3}$	$10^{5} \div 10^{6}$	$10^{-5} \div 10^{-4}$
Магнитные . . . (12)	$10^{-6} \div 10^{-4}$	$10^{-3} \div 10^{3}$	$10^{4} \div 10^{7}$	$10^{-3} \div 10^{-2}$

Key: (1). Form of relay. (2). Power of function of W. (3). Controlled power W. (4). Control ratio. (5). Triggering time of s. (6). Electromagnetic. (7). Polarized. (8). Magnitoelectric. (9). Induction. (10). Electronic. (11). Ionic. (12). Magnetic.

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Depending on overall dimensions and weight contemporary airtight relays for radio-electronic equipment can be divided into three groups: a) the miniature/small relays with six or four stud switches, which have the space of less 40

cm^3 and the weight of less 150 g; b) the miniature relays with two stud switches, which have space from 3.5 to 8 cm^3 and weight from 10 to 30 g and c) the subminiature relays with one or two stud switches, which have the space of less 3.8 cm^3 and the weight of less 10 g.

V-2. Electromagnetic relays.

Theory and the calculation of all varieties of the relays, used in automation and telemechanics, briefly are set forth in the common/general/total courses of the cell/elements of automatic and telemechanical equipment [1-2]. In this book are examined in more detail in essence only electromagnetic relays, used mainly in radio-electronic equipment for automation and equipment for electrical communication.

Electromagnetic they are called the relays whose action is based on interaction between ferromagnetic armature and the magnetic field of the current-passing winding. Electromagnetic relays are divided into neutral and those who were polarized.

In electromagnetic neutral relays working magnetic flux is created with the aid of windings. The work of relay depends only on the value of the current, which takes place through the winding, and it does not depend on direction of flow.

The polarized electromagnetic relays have two independent magnetic fluxes: the polarizing and worker.

The polarizing magnetic flux is created largely by the permanent magnet (sometimes by electromagnet), and working flow - by the current-passing winding. Therefore the action of polar relays depends on the direction of direct current in inducing winding.

The construction of electromagnetic (neutral) relays consists of four basic parts: the stationary part of the magnetic circuit with core, winding (arrange/located usually on core), the moving element of the magnetic circuit - armature and contact system.

Depending on the location of armature and character of

effect on it of magnetic flux, electromagnetic relays are divided on: with relay with the external attract/tightened armature (valve type relay), relay with the pulled armature (solenoid type relay) and relay with the external transversely moving (rotary) armature (rotary type relay).

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Figure V-2 shows the outlines of some versions of the magnetic systems of relay of valve (a), solenoid (b) and rotary (c) types.

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The majority of the relays, used in radio-electronic equipment for automation and equipment for communication/connection, until recently had valve type magnetic system. Received at present wide acceptance rotary type magnetic systems.

The short description of the constructions of the fundamental types of these relays is given in the first chapter.

In recent years received wide acceptance the electronic, semiconductor and magnetic noncontact switching equipment/devices. However, in the majority of cases, they cannot replace electromagnetic relay. Is explained this to the fact that the electromagnetic relays have very low contact resistance of the locked contacts (less than 0.1 ohm), the virtually infinite resistor/resistance of the circuit of dead contacts (more than 1000 MΩ), allow/assume considerable short-term overloadings in the circuits of contacts and windings, they make it possible to simultaneously switch several independent (galvanically not connected) electrical circuits (2, 4, 6, 8 and more than), have relatively smaller overall dimensions, smaller weight and considerably lower cost/value.

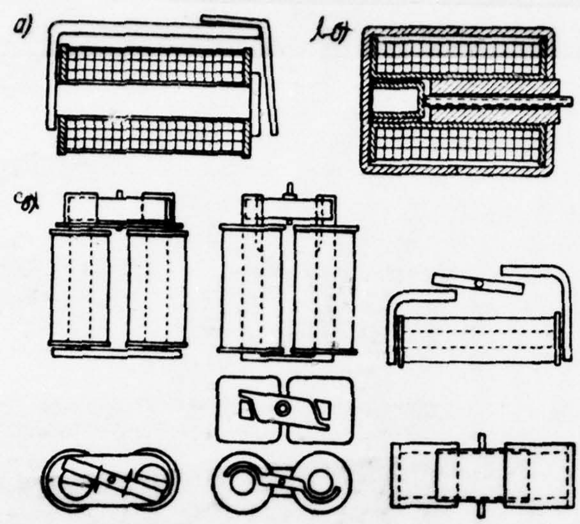

Fig. V-2. Outlines of magnetic systems of relay: a) valve type; b) solenoid type; c) rotary type.

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Miniature vibrating-reeds relay have triggering time of approximately 0.5 ms and a releasing time less than 0.1 ms. The service life of vibrating-reeds relay with very light loads is within the limits from $2 \cdot 10^8$ to $1 \cdot 10^9$ commutations.

Semiconductor relays have conductive coupling between

governing and performing circuits; if necessary for the commutation of several circuits, the semiconductor devices strongly become complicated. A voltage drop across the switching device is very great (1.0-1.5 V), its resistor/resistance is also great (more than 2 ohm); in the extended state the resistor/resistance of performing circuit, on the contrary, is small (1-10 MΩ). Furthermore, transistors are very sensitive to the current variations and voltages, which exceed nominal values, and they are characterized by small thermal stability. Therefore the semiconductor switching devices have great advantage over electromagnetic relays only when is required very high speed cf response and release/temperings, order of dozens of microseconds, since triggering time of electromagnetic relays approximately 100-1000 times no longer is within the limits from 1 to 25 ms.

V-3. Fundamental requirements, presented to relay.

To the electromagnetic relays, used in radio-electronic equipment and equipment for communication/connection, are presented very many the most diverse requirements which

usually cannot be completely satisfied in one universal construction. These relays must have small overall dimensions and light weight, a sufficiently large quantity of performing contacts (contact springs), the small required power (high sensitivity), high reliability, the large switched power, short triggering time and release/tempering, the possibility of obtaining the considerable time dilation of release/tempering or function (of the telephone relay), large service life, large wear resistance, the rigid and rugged construction, which ensures sufficient vibration- and impact resistance, reliable and stable work during the considerable fluctuations of ambient temperature and humidity during long time, and it is also possible simpler and cheaper in structural design.

Therefore for purposes of automation, telemechanics and communication/connection, it is necessary to have a large quantity of different types of relay.

The contemporary electromagnetic relays of communication/connection have to 24-30 contacts (to 48-60 contact springs). The specific volume of these relays is approximately 8.7 cm^3 to one pair of contact springs. Power of function with one circuit closing contact (the

"sensitivity" of relay) by 12 mW. Shortest triggering time and release/tempering 2-3 ms.

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Wear resistance of relay of up to 250-500 million commutations (triggerings) and the service period is up to 20-40 years. **Shortest triggering time of the high speed electromagnetic** relays of automation of approximately 0.5 ms (of the breaking contact) and 1.0 ms (of circuit closing contacts). The releasing time of these relays is respectively equal to 0.3-1.0 ms.

Many types of contemporary electromagnetic relays for radio-electronic equipment for automation are manufactured in pressurized/sealed performance and are designed for operation in mobile units with considerable vibrations and impacts, and also during the large fluctuations of ambient temperature, humidity and atmospheric pressure.

Contemporary miniature/small vibration-proof airtight electromagnetic relays for radio-electronic equipment with six stud switches, which commutate direct current to 2(5) A with voltage 28 V (or alternating current of up to 2A - 115 V), have space 22-34 cm^3 and weight 70-130 g. Power,

consumed during function, 0.5-0.9 W.

Contemporary miniature airtight relays with two stud switches, which commutate current to 2 A - 28 V, have space of approximately 5 cm^3 and weight 14-18 g. Power, consumed during function, 0.15-0.25 W. Great winding impedance 20 000 ohm. Triggering time and release/tempering is less than 5 ms. Subminiature airtight relays with one stud switch, which commutates current 0.5-1.0 A with voltage 30 V, have space 0.8 cm^3 and weight of approximately 3 g. Required power during the function of relay of approximately 0.1 W, the minimum current of function of approximately 6.5 mA. In the open performance subminiature relays have weight of approximately 1 g.

Vibrating-reeds relay with one circuit closing contact are characterized by small and stable contact resistance (0.03-0.2 ohm), high speed of response (0.5-2.0 ms), by prolonged service life with very light loads (10^8-$2 \cdot 10^9$ cycles) and by the low required power (0.02-0.20 W).

Electromagnetic relays are the sufficiently complex mechanism, which consists of a large quantity of parts. For example, an electromagnetic relay of the type RPN has 90

parts (28 different types), a relay of the type RKN has 121 parts (31 types), and a relay of the type RS-13 has 165 parts (35 types).

For the production of these relays, is required more than ten different designations of materials.

A quantity of relays, used in equipment for automation, especially in equipment for automatic telephone communication, is very great. For example, on urban district automatic telephone station by capacitance/capacity into 10000 numbers it is mounted to 70000 relays.

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At present in the USA by the production of relay are occupied about 200 firms which are released more than 1000 different types of relay [1-26]. According to the data of the Ministry of the Trade of the USA for 1963, were sold about 35 million relay for radio-electronic equipment by common/general/total cost/value into 210 million dollars. In this number do not enter telephone relays for an automatic telephone station. Firm "Western Electric" in the USA manufactures more than 30 million telephone relay per

annum [1-38, 1-39].

Development of relay technology must be directed along the path of a further improvement in the operating parameters; decrease in the overall dimensions of relay; increase in the sensitivity; decrease in triggering time; increase in the switched power and service life of relay and increase in their reliability because of the improvement of the construction of magnetic and contact system; the application/use of new magnetic, insulating, contact and structural materials and use of new vacuum-tube technology of production. It is necessary also to work on the improvement of construction and a decrease in the cost/value of relay because of the wide application of the contemporary automated production and control processes and decrease in the operating time of assembly, adjustment and tests of relay.

Furthermore, it is necessary to conduct extensive experimental work on the investigation of wear resistance of contacts from different materials as a function of commuted currents and voltages, to the determination of the limits of the oscillations of contact resistance with different electrical loads under different operating conditions and to the determination of the lower limits of commuted currents and stresses for the different types of relay.

Page 13.

Part One

Neutral Relays.

Chapter One.

SHORT DESCRIPTION OF THE CONSTRUCTIONS OF RELAYS.

1-1. Relays with circular core of type RKN.

Relay with a circular core of the type RKN is applied in equipment for automation, operated for the movable objectives, and also in the different units of communication/connection, signaling and automation. The general view of this relay is shown in Fig. 1-1.

The magnetic system of relay consists of the housing of L-shaped form, bent of sheet steel by thickness 4 mm, core by diameter 9 mm and the armature of L-shaped form.

For a decrease in the reluctance of the joint of housing with armature, the end/lead of the housing is equipped by "knife" support for armature in the form of triangular prism. Width of housing 20.6 mm, the height/altitude of "knife" support 8.2 mm.

Front/forward end of the core has the pole piece as diameter 15 mm, the calculated length of core 70 mm. Core is fastened to housing with the special steel nut of cylindrical form.

Armature is bent made of sheet steel by thickness 2 mm, it is equipped by the brass plug of loosening and by two ebonite pins for the transmission of effort/forces to the driving/moving plugs of contact groups. Width of armature 20.6 mm.

Against the bearing edge support, the armature is pressed by steel cylindrical spring with the aid of special screw/propeller. The adjustment of course is conducted by means of the bending of armature in special attachment.

The parts of magnetic circuit are made made of steel of brand EA and are covered with nickel.

For absorbing the fluctuations of armature and elimination of the vibration of contact springs in the work of relay, the front/leading jaw of coil is made of red copper (thickness of jaw 1.6 mm).

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Winding is isolate/insulated from copper jaw by supplementary getinax jaw.

The rear jaw of coil is made out of getinax by thickness 3 mm, into this jaw it is pressed from two to five leading-out plugs for the soldering of the end/leads of the winding.

The contact system of relay of the type RKN consists of one or two contact groups; each group can have from two to nine contact springs. Contact springs have in the middle part width 4 mm and calculated length 38 mm, they are manufactured from extra-hard white copper with thickness 0.35 mm.

The end/leads of the springs are bisected and equipped by two contacts of hemispheric form (by diameter 1.6 mm) from silver of brand Sr 999.

With large loads are applied the contacts from platinum or its alloy with iridium.

The springs of relay rest on special stop block of complex form from plastic, strengthened by two screw/propellers on housing between groups. The normal running of the armature of relay 0.8 mm, the height/altitude of the plug of loosening vary within the range of 0.1 to 0.5 mm.

In the normal position of relay, the housing and contact springs are arrange/located in vertical planes.

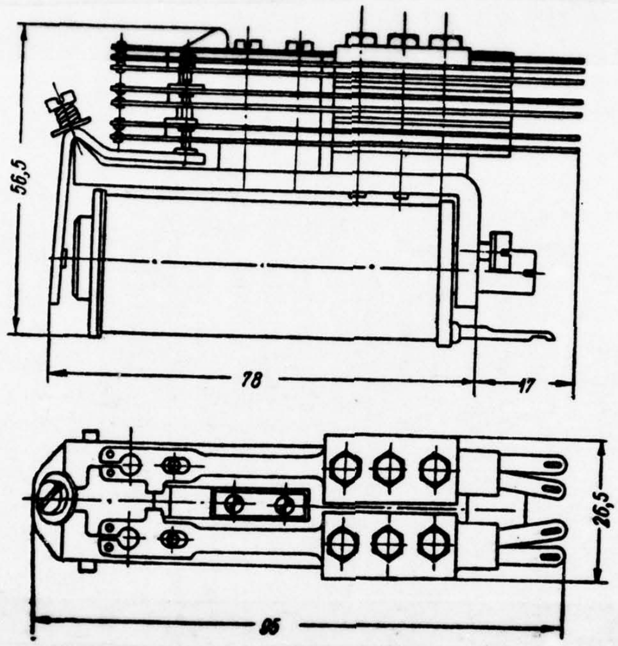

Fig. 1-1. Relays of type RKN (normal).

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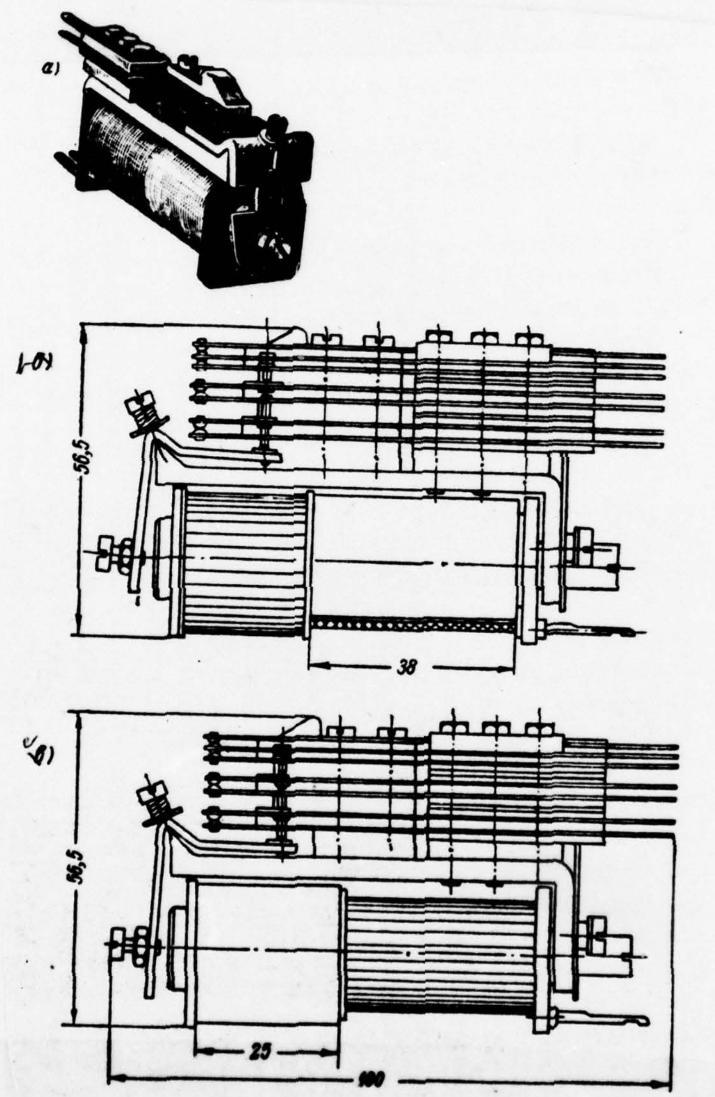

Fig. 1-2. Relays of type RKN: a) pulse; b) retarded for release/tempering; c) retarded for function.

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Relay is fastened to board by two screw/propellers (diameter 3 mm).

The high speed (test) relays of the type RKN have a core without the pole piece. The front/leading jaw of the coil of these relays is made out of getinax.

For a decrease in the distortions of the relayed momentum/impulse/pulses, a pulse relay of the type RKN (Fig. 1-2a) has special armature with the reduced section (2 x 6 mm) in the middle part (armature with twc grooves).

To pulled positions the narrow passage of armature is saturated and limits flow value in the magnetic circuit of relay. Therefore the releasing time of relay decreases and in its value approaches triggering time.

Time-lags relay of the type RKN (Fig. 1-2b; 1-2c) have on core massive plugs of red copper (as diameter 25 mm by length 12.8, 25.5 or 38 mm).

In the relays, retarded for release/tempering, this plug is arrange/located at foundation (from behind coil), while in the relays, retarded for function, on the contrary, of the end/lead of the core (in front of coil).

For the growing magnetic flux the copper plug, arrange/located in front of coil, is the electromagnetic screen, which retards the build-up of flow in the clearance of relay.

For the adjustment of releasing time, time-lags relay are frequently supplied with the adjustable plug.

The contacts of relay are maintain/withstood 10^7 cycles (functions) with resistive load 0.2 A - 60 V direct current either 110 V alternating current, 10^5 cycles with load 2 A - 36 V or 0.2 A - 300 V direct current.

Relays of the type RKN are intended for operation at the temperatures of surrounding air from -40 to +40°C (+60°C), relative humidity to 98o/o at temperature of 20 ± 5°C and with vibration of the places of attachment with

frequency 30 ± 2 Hz during acceleration to 1.8 g. Relays maintain/withstand testing for impact strength during acceleration 15 g (2000 impacts).

The insulation resistance of windings and contacts of relay with respect to housing and among themselves under normal conditions is more than 500 MΩ, but after the stay for 48 h under conditions of humidity 95 ± 3o/o - it is not less than 10 MΩ. Insulation of windings and contacts maintain/withstands with respect to housing and between themselves during 1 min testing voltage 500 eff. V at frequency 50 Hz.

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1-2. Relays of type RKM-1.

The relays of the reduced overall size with a circular core of type RKM-1 are intended for a work in movable and movable equipment for automation; it can also be applied as linear and ringing-trip relay on automatic telephone station. The general view of relay of type RKM-1 is shown in Fig.

1-3.

By the construction of the magnetic system of relay of type RKM-1, it is similar on relay of the type RKN, but it is characterized by from it smaller size/dimensions and does not have knife edge for armature.

The housing of relay of type RKM-1 is bent made of sheet steel by thickness 2 mm, the width of housing 20 mm. Diameter of core 7 mm, length its 55 mm. Diameter of the pole piece 11 mm.

Armature is made made of sheet steel by thickness 1.2 mm, it is held in housing by flat/plane bronze plate.

The jaws of coil are made out of getinax, into the rear jaw of coil, are pressed four of leading-out plugs for the soldering end/leads of the winding.

The contact system of relay consists of one, two or three contact groups, assembled in one common/general/total packet.

Each group can have from two to five contact springs

of trapezoidal form; the width of spring of foundation 5 mm, calculated length 39 mm. For an increase in the flexibility, movable springs available in foundation rectangular opening/aperture as width 2.5 mm.

The movable springs of relay are manufactured from white copper or bronze with thickness 0.3 mm, motionless - frcm white copper by thickness 0.8 mm.

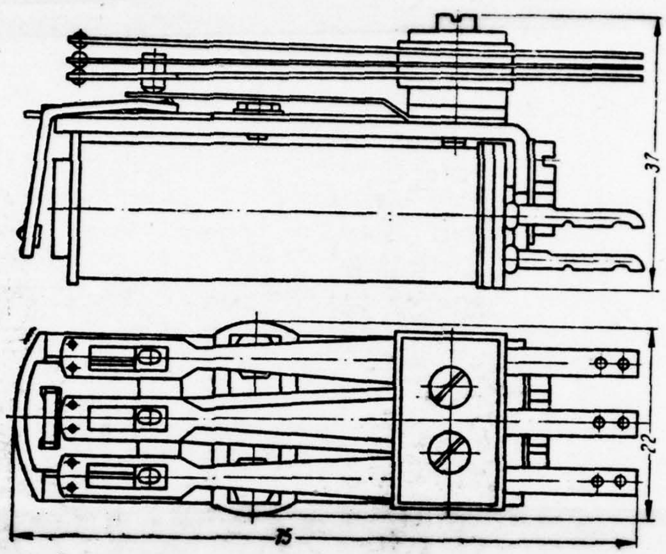

Fig. 1-3. Relays of type RKM-1.

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The backstops of relay do not have, movable springs rest on block/backings (supporting springs) from white copper by thickness 0.8 mm. Contact springs have two contacts by diameter 2 mm from silver of brand Sr 999. The normal running of the armature of relay 1.1 mm, the height/altitude of the plug of loosening 0.1-0.2 mm.

Relay is fastened to board by two screw/propellers

(diameter 2.6 mm).

Time-lags relay of type RKM-1 have on core (under winding) quadrature winding from bare red copper wire by diameter 0.5 mm. Quadrature windings are fulfilled by height/altitude 1 or 2 mm (2 or 4 layers of wire).

The armature of relay of type RKM-1 returns to initial position with the aid of flat spring from aluminum bronze with section 0.3 x 8 mm, that creates small torque/moment. The sensitivity of relay of type RKM-1 without return spring with light loads is almost two times more.

The service life of the contacts $5 \cdot 10^6$ of cycles with resistive load 0.2 A are 60 V direct current or 110 V alternating current and 10^5 cycles with load 2 A - 36 V direct current.

Relays of type RKM-1 are intended for operation at temperature of $\pm 40°C$, humidity to 98o/o at +20°C and vibration with frequency 30 Hz during acceleration 1.8 g. The impact strength of relay 15 g (2000 impacts).

1-3. Relays of the type RKMP.

A relay of the type RKMP is intended for operation in the mobile units of automation, signaling and communication/connection under conditions of the fluctuations of the temperature of surrounding air from -60 to +70°C, increased relative air humidity to 98o/o at temperature from +15 to +40°C, the vibrations of the places of the attachment of relay with frequency from 20 to 70 Hz, during accelerations to 5 g, and from 70 to 80 Hz during acceleration 2.5 g, linear (centrifugal) accelerations to 10 g and atmospheric pressure to 64 mm Hg. Relay maintain/withstands vibration test in the range of frequencies from 20 to 70 Hz with acceleration 8 g and impact strength during acceleration 75 g (4000 impacts).

The general view of relay of the type RKMP is shown in Fig. 1-4.

By the construction of magnetic circuit and contact system of relay of the type RKMP, it is similar on relay of the type RKN, but is characterized by from it somewhat smaller size/dimensions and the device of separate parts.

Core and the housing of relay of the type RKMP have length 54.5 mm, instead of 70 mm. The thickness of housing 3 mm, the end/lead of the housing does not have knife edge. Armature is suspend/hung from two bronze plugs, it is balanced relative to rotational axis by counterweight and is held by the brass framework. Contact springs are isolate/insulated by separators of plastic; their working length 25 mm instead of 38 mm of relay of the type RKN.

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The contact system of relay consists of one or two contact groups; each group contains from two to nine contact springs. Contacts dual, from silver or platinum. The coil of relay has five leading-out plugs and can consist of three windings. Time-lags relay have on core quadrature winding of six or eight of series of bare copper wire as diameter 0.5 mm.

Insulation of contact springs maintain/withstands testing voltage 1100 eff. V, and windings 500 eff. V, alternating current by frequency 50 Hz.

The insulation resistance of windings and contact

springs under normal conditions is more than 500 MΩ, also, with the increased humidity of more than 10 MΩ.

The contacts of relay are maintain/withstood 10^5 cycles with resistive load 2 A - 32 V or 0.1 A - 300 V direct current, and also 10^7 cycles with load 0.2 A - 60 V.

A relay of type RKMP-1 has additionally steel shielding jacket (screen), it is manufactured with the number of contact springs not more than six.

The overall dimensions of the relay 30.6 x 49.4 x 87.5 mm, weight 300 g.

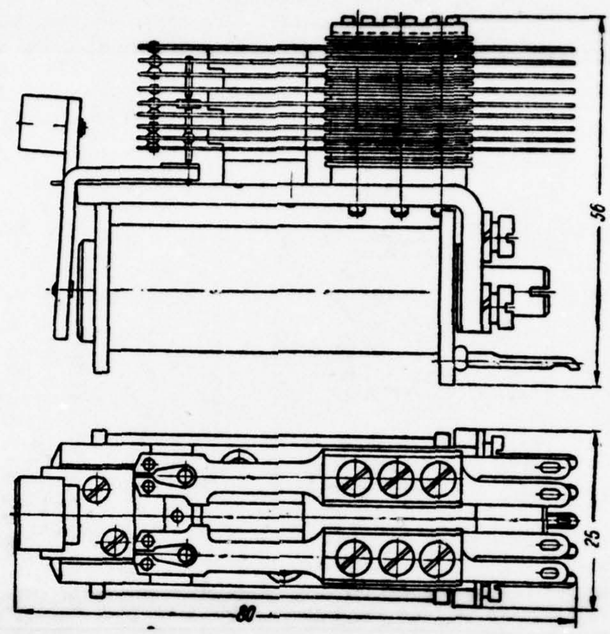

Fig. 1-4. Relays of type RKMP.

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1.4. Relays with a flat/plane core of the type RPN.

In equipment for automation, telemechanics and communication/connection, operated under stationary conditions, widest use obtained relay with a flat/plane core of the type RPN whose general view was shown in Fig. 1-5. The magnetic system of relay consists of the die-forged/stamped core of the rectangular cross section (4 x 10.5 mm), made solid with foundation, and the flat/plane armature of U-shaped form, side-by-side to core and enveloping coil. Length of armature 90 mm, section its 1.8 x 23 mm. Calculated length of core 74 mm, the working surface of pole 9.4 x 17 mm. Armature is pressed against the foundation of relay by flat spring and rests on special supporting/reference corner iron (backstop), attached under coupling group.

Core and armature of relay are manufactured from mild, annealed transformer steel of brand EA. For corrosion protection, the core and the armature of relay are covered with nickel.

To the core of relay, are mounted two jaws of the rectangular form made of getinax (by thickness 1.5 mm), that form framework/body (coil) for the winding of relay. The front/leading jaw of coil serves simultaneously as support for the contact springs of relay. From opposite coil side on the basis, is fastened the coupling group, which provides five of leading-out springs for the soldering of the end/leads (conclusions) of the windings of relay.

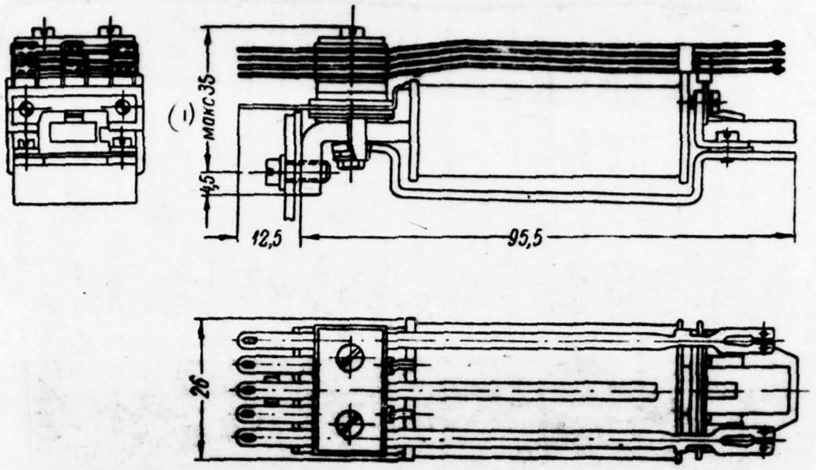

Fig. 1-5. Relays of the type RPN.

Key: (1). max.

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The winding of relay is insulated from core by the silk varnished insulating cloth of brand LSh-1 or lacquered paper by thickness 0.1 mm (1 1/2 layers). For the windings of relay, is applied red copper wire with enamel insulation of the brand PEL by diameter from 0.05 to 1.0 mm, but is most frequently utilized wire by a diameter from 0.08 to

0.35 mm.

Contact to the system of relay of the type RPN consists of one, two or three contact groups, collected in one common packet, tightened by two screw/propellers. Each group can have from two to six contact springs.

Contact springs have width 3.5 mm and calculated (useful) length 74 mm. They are manufactured from extra-hard German silver brand MNTs-20 with thickness 0.5 mm. Contact springs are isolate/insulated from each other by separators of getinax by thickness 1.0 mm.

The end/leads of the springs are bisected and equipped by the contacts of hemispheric form (diameter 2 mm) from silver of brand SR 999. The contacts of the relays, governing the circuits of selector (1a-60 v), are manufactured from platinum or explosive of alloy with iridium.

The transmission of effort/forces from armature to contact springs is realized with the aid of the driving/moving getinax plate (backstop), strengthened to the brass bridge which is screwed on to armature by two

screws. These screw/propellers simultaneously serve for the attachment of nonmagnetic antistick strip, which prevents armature from scaling.

Bridge has the special flange, which rests on the core of relay and serving for adjustment and limitation of the course of armature.

The course of armature is establish/installed within limits from 1.1 to 1.5 mm depending on the character of contact groups; for more complex groups is required the course of armature 1.3-1.5 mm.

Normal thickness of nonmagnetic antistick strip 0.2-0.3 mm, fine/thinner nonmagnetic antistick strips, 0.1 mm, are applied for time-lag relay. In pulse relays for a decrease in the releasing time, are used nonmagnetic antistick strips by thickness 0.5-1.0 mm.

One of the deficiency/lacks in the relay is the unbalanced and heavy armature (weight together with bridge 34d), that has low frequency of natural oscillations.

In the normal position of relay, the plane of armature

(and of contact springs) must be arrange/located vertically in order to avoid the gravity effect of armature on the sensitivity of relay and to decrease the becoming dusty of contact surface.

The relays are intended for use only in stationary equipment, since it is sensitive to divergence from vertical line and to external jolts.

Relays of the type RPN simply by construction, its almost all parts die-forge/stamped; it is approximately two times cheaper than the relay of the type RKN. Relay is fastened to board by one screw/propeller (diameter 4 mm), its housing from board is not isolate/insulated.

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Time-lags relay of the type RPN have core (under inducing winding) quadrature winding from bare copper wire by diameter 0.5 mm. Depending on the degree of retarding/deceleration/delay, quadrature winding has the height 1.2 or 3 mm (2.4 or 6 layers of wire). At the end/leads of the cores of time-lags relay, are made the corresponding designations: K1, K2 and K3.

For pulse pairs which commutate high currents (2-3a), they are applied by relay RPN with special tungsten contacts (diameter 2 mm).

Operating voltage of contacts and windings of relay RPN by 60 v. Service life of the contacts of 10 million functions with resistive load by current 0.2a and voltage 60 v. A relay of the type RPN is intended for a work under normal conditions with ambient temperature from +10 to +35° C and relative air humidity from 45 to 75o/o (θ_0 = 20 ± 5°C).

The fundamental parameters of relay of the type RPN are given below in Table 1-2.

1-5. Miniature/small electromagnetic relay of the type RS-13.

Miniature/small electromagnetic relay of the type RS-13 is intended for use in equipment for communication/connection, signaling and automation, working

under conditions of the fluctuations of the temperature from -50 to +40°C with the increased humidity (to 98o/o) and vibrations with acceleration to 4 g at frequency 45 Hz.

The general view of relay of the type RS-13 is shown in Fig. 1-6. The construction of magnetic relay circuit is similar to relay of type RKM-1 but it has another attachment of armature and smaller size/dimensions.

The housing of relay is bent made of steel by thickness 2.5 mm, width its 16 mm. Front/forward end of the housing is bent at an angle of 45° and it is sharpened under the prism to blade of which is pressed the armature.

The diameter of core is equal to 7 mm, length 40 mm. For sensitization, the core few loaded relays has the pole piece as diameter 11 mm.

Armature has thickness 1.2 mm; to the forward section of the armature, is riveted steel plate by size/dimension 13 x 15 mm. The flat/plane return spring of the L-shaped of forms from the phosphor bronze (by thickness 0.25 mm), strengthened to the brass limiter of complex form, tightly

presses armature to support and holds it in initial position during vibration. Pressure of return spring on armature of approximately 100 g.

To core are mounted two jaws out of getinax. In rear jaw it is pressed from two to the heel of leading-out plugs for the soldering of the end/leads of the winding.

The contact system of relay consists of two contact groups each of which can have from two to nine contact springs. Contact springs are made from the phosphor bronze, their length 15 mm section 0.2 x 5 mm, but because of large grooves the useful width of spring is strongly decreased.

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Springs are equipped with dual contacts of diameter 2 mm. Motionless springs lie/rest on supporting springs from brass by thickness 0.5 mm. Course of the armature of relay with small and average loads 0.75 mm, with high 0.9-1.1 mm; the height/altitude of the plug of loosening 0.1-0.2 mm.

Relay is equipped by the rear fender made of steel and shielded detachable aluminum jacket which is held by U-shaped spring from steel wire. On jacket is designated

the circuit of coil leads and contacts. It is fastened with relay to board by two screw/propellers.

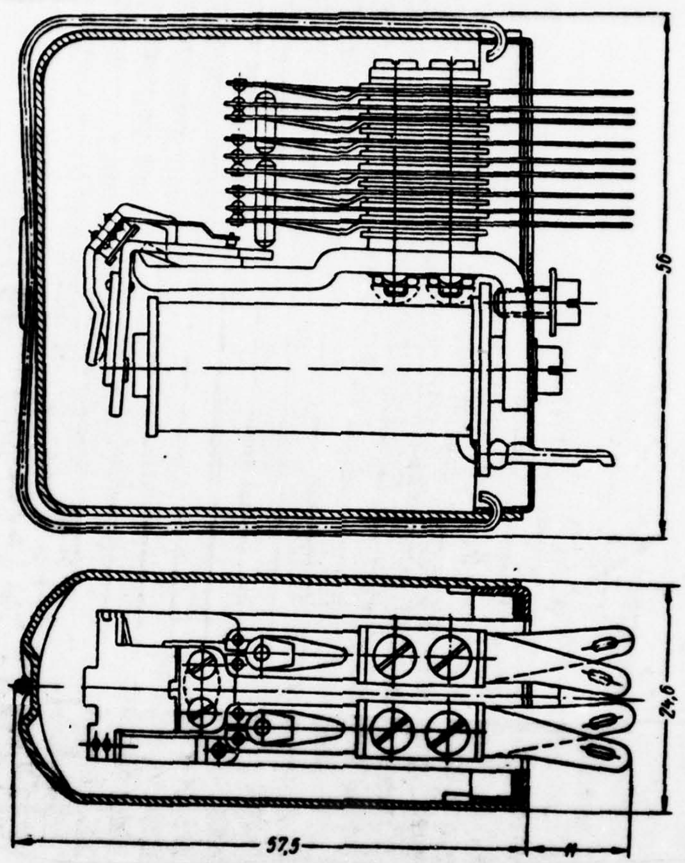

Fig. 1-6. Relays of the type RS-13.

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1-6. Miniature/small relay of the type RSCh-52.

A relay of the type RSCh-52 is the modernized relay of the type RS-13, which is characterized by larger vibration resistance and the wider limits of operating temperatures. It is intended for operation during changes in the ambient temperature from -60 to +70°C, relative humidity to 98o/o (at 20°C), the vibration of the places of attachment with frequency from 20 to 80 Hz and acceleration to 10g, centrifugal accelerations to 20g and atmospheric pressure to 15 mm Hg.

A relay of the type RSCh-52 is maintain/withstood 2000 impacts with acceleration 75g, while relay of the type RS-52 - 250 impacts with acceleration 150g. The general view of relay of the type RSCh-52 is shown in Fig. 1-7.

The magnetic system of relay of the type RSCh-52 is a little intensified, the diameter of core equal to 8 mm instead of 7 mm of relay of type RS-13, the thickness of housing 3 mm instead of 2.5 mm.

Armature is balanced relative to rotational axis with the aid of counterweight and has another attachment.

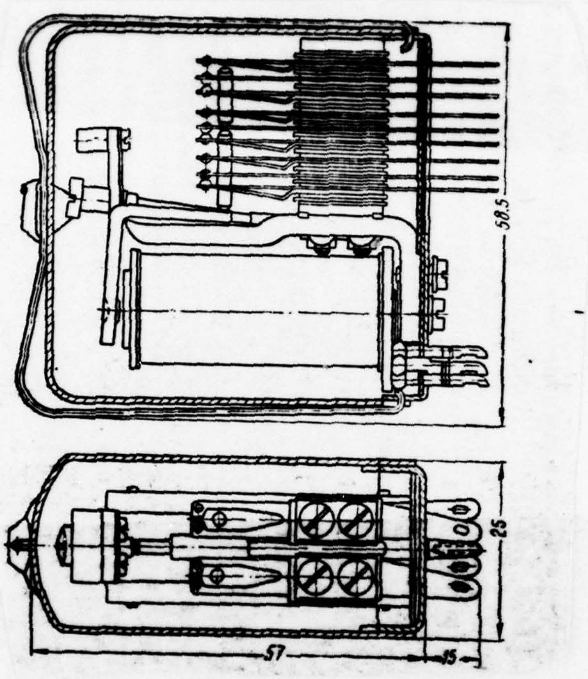

Fig. 1-7. Relays of the type RSCh-52.

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The full load of the relay of 18 contact springs. The winding of the relay, which has full load, is made from the wire of brand PEV-1.

For an increase in the leakage paths of the separator

of contact groups, they have opening/apertures of different size/dimensions, and they are asymmetric with respect to the axis, passing through these opening/apertures. Between contact springs they run themselves on three separators, which protrude by edges into different sides. Contact springs are shielded from random damage by two steel cover plates, strengthened on top above groups. Insulation of winding and contact springs is intensified and maintain/withstands testing voltage 1100 eff. V.

The contacts of relay are maintain/withstood 10^5 cycles with the resistive load 2a - 28v or 1.25a-300v of direct current.

A relay of the type RSCh-52 is equipped by the rear fender and it is placed into shielding aluminum jacket. In this it differs from relay of the type RS-52.

1-7. Miniature/small relay of the type RMU.

A relay of the type RMU is intended for the commutation of electrical circuits to miniature/small movable

equipment for automation, signaling and communication/connection with the fluctuations of temperature from 60 to +85°C, relative humidity to 98o/o with 40 ± 5° C, vibration of the places of attachment with frequency from 16 to 300 Hz and acceleration to 10g, centrifugal accelerations to 25g and atmospheric pressure to 15 mm Hg.

Relay is maintain/withstood 250 impacts with acceleration until 150g.

The general view of relay of the type RMU is shown in Fig. 1-8.

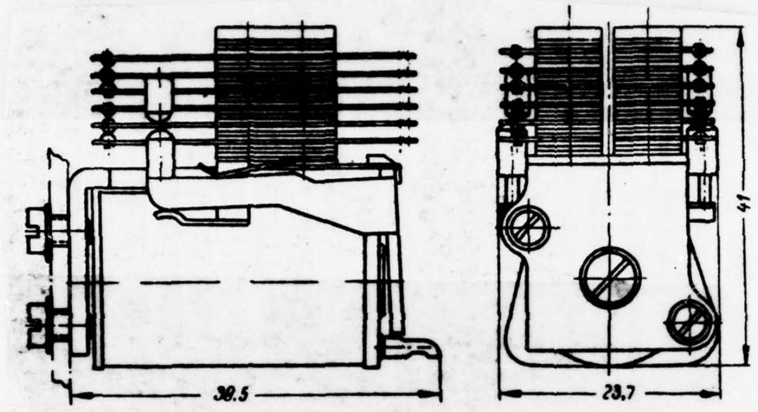

Fig. 1-8. Relays of the type RMU.

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The magnetic system of valve type relay, the diameter of core 8 mm, length 32 mm; the thickness of housing 2 mm, width its 17.5 mm, the thickness of armature 1.3 mm. Coil leads and contact springs are arrange/located from armature.

Armature have on each side of two elongated levers with the insulating bushes at end/leads for displacement of movable contact springs.

The relation of the arm of armature and levers is equal to 2.2. Course of armature 0.4 mm. The plug of loosening armature does not have. Return springs flat/plane, the pressure of return springs 20-30 g.

Armature is held in housing with the aid of special flat spring, which limits the lateral displacement of armature. The contact system of relay consists of two groups; each group can have from two to six contact springs. Contact springs are made from white copper. Movable springs have working length 21 mm, width 3.2 mm and thickness 0.3 mm. Motionless springs have trapezoidal form and thickness of 0.45 mm. The coil of relay has two or four conclusions. Insulation of winding and contact springs maintain/withstands testing voltage 1000 eff. V.

The contacts of relay are maintain/withstood 10^5 cycles with the resistive load 1a-30v, or 0.1a-300v of direct current, and also 1a-115v alternating current 400 Hz under normal conditions (with atmospheric pressure 40 mm Hg load decreases to 0.1a-150v, and with 15 mm Hg, is allow/assumed load only 1a-30v).

Relay with two intensive stud switches of the type RMU-S is maintain/withstood 10^5 cycles with the resistive load 5a-30v or 0.05-600v of alternating current by frequency 400 Hz, while relay with one circuit closing contact of the type RMU-S (double-break) is maintain/withstood 10^5 cycles with load 10a-30v.

Time-lag relay of type RMU-3 has of core massive copper plug as length 17 mm by diameter 19/8 mm. Releasing time of time-lag relay with stud switch of approximately 30 ms.

1-8. Sealed relay of the type RMUG.

A relay of the type RMUG is sealed relay of the type RMU. Its general view is shown in Fig. 1-9. Sealing/pressurization is realized with the aid of the sealed metallic (steel) jacket and circular glass socket into which it is scalded 14 soldering hooks from Kovar alloy for the conclusion of the circuits of contact springs

and winding. For attachment to the board of relay, it has on the basis three nut bolts. Outside relay it is painted by gray color/paint. After sealing the internal volume of relay is filled with dry nitrogen.

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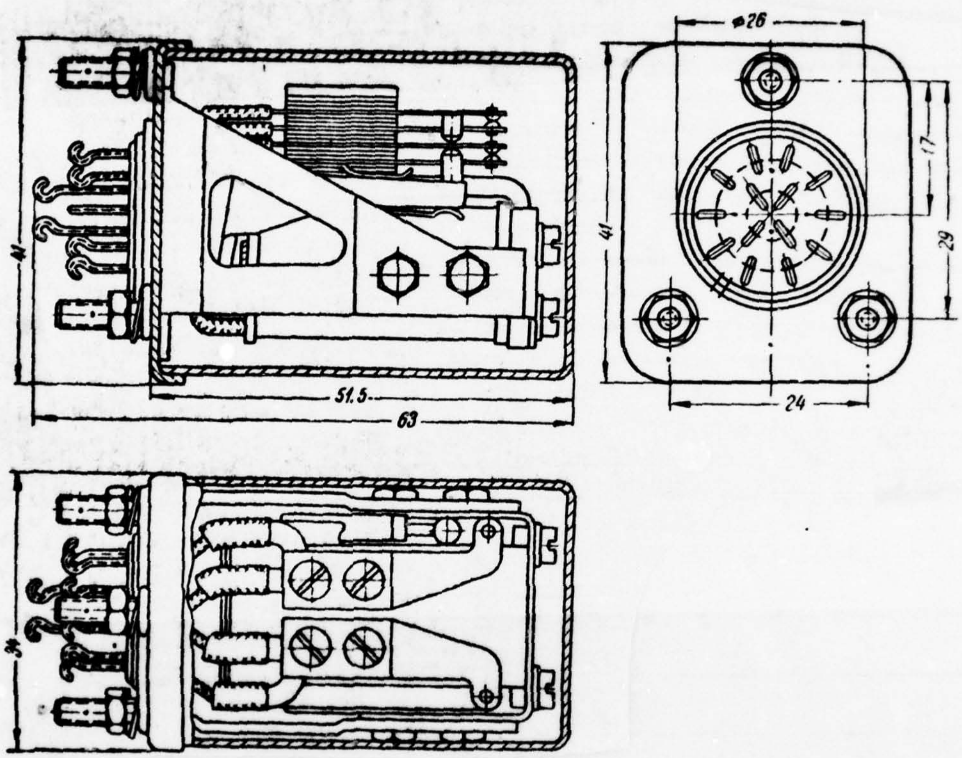

Fig. 1-9. Relays of the type RMUG.

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Due to the presence of intermediate attachment within jacket, the vibration resistance and the impact stability of relay of the type RMUG are less than relay of the type RMU.

Relays of the type RMUG it is possible to operate with temperatures from -60 to +85°C, relative humidity to 98o/o at 45 ± 5°C, vibrations with frequency from 16 to 80 Hz and acceleration to 4 g, linear accelerations to 8 g and atmospheric pressure to 15 mm. Hg. Relay maintain/withstands vibration test at frequency 50 ± 5 Hz and upon acceleration 4 g ($5 \cdot 10^6$ cycles), also, for the impact strength during acceleration 4g (10^4 impacts with the frequency of 80 impacts per minute).

The period of service of the contacts of the relay of 10^5 cycles with resistive load 1a — 27v either 0.1a-300v direct current or 1a-115v alternating current (400 Hz).

The testing voltage of insulation under normal conditions 1000 eff. V, with atmospheric pressure 41 mm Hg - 500 V and below 40 mm Hg - 300 V.

Insulation resistance under normal conditions is more than 5000 MΩ, after stay for 48 h with the increased humidity it is not less than 100 MΩ.

In all remaining parameters of relay of the type RMUG, it does not differ from relay of the type RMU.

Dimensions of relay of the type RMUG are 35 x 42 x 65 mm; weight 160 g.

1-9. Sensitive sealed relay of the type RDChG.

A relay of the type RDChG is the sensitive electromagnetic relay with one stud switch, intended for operation in movable equipment for automation during the fluctuations of temperature from -60 to +85°C, to tropical humidity (relative humidity to 98o/o and temperature to +40°C), vibration with frequency from 16 to 80 Hz and acceleration to 4g, centrifugal accelerations to 8g and atmospheric pressure to 41 mm.

Relay is maintain/withstood 1000 impacts with acceleration 4g.

The general view of relay of the type RDChG is shown in Fig. 1-10.

The magnetic system of relay has U-shaped form it consists of two coils with cores, closed by flat/plane armature. Cores, foundation and the armature of relay are made from permalloy, brand 50 N.

The contact system of relay is rigid. Fixed contacts are fastened on two adjustable screw/propellers, arrange/located on the brass corner irons, riveted to a plate from Textolite. The breaking contact is made made of tungsten, circuit closing contact - from silver. Movable silver contact is soldered to the brass lever of armature. Armature is balanced relative to rotational axis and has spiral return spring.

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Gap between the contacts 0.09 mm. Pressure in opening contact 50 g in closing - 125 g.

The jacket of relay is made from brass and it is painted in gray color. Sealing/pressurization is realized with the aid of glass base with five leading-out Looks.

The power, consumed by relay during function, is not more than 13.2 mW (spill current not more than 2.5 mA with winding impedance 2100 ohm and turn number 2 x 11000 wires by diameter 0.08 mm of the brand PEL, the current of release/tempering is not less than 0.6 mA). The relay reset coefficient is not less than 0.24. With an increase in the permanent air gap between core and armature to 0.3-0.4 mm (instead of 0.05-0.1 mm) the relay reset coefficient grow/rises to 0.65-0.75, but the power of function increases to 35-50 mW (AW_c = 86-102). Great winding impedance of relay 14000 ohm with wire by diameter 0.05 mm of the brand PEL; the turn number of the winding 2 x 28000.

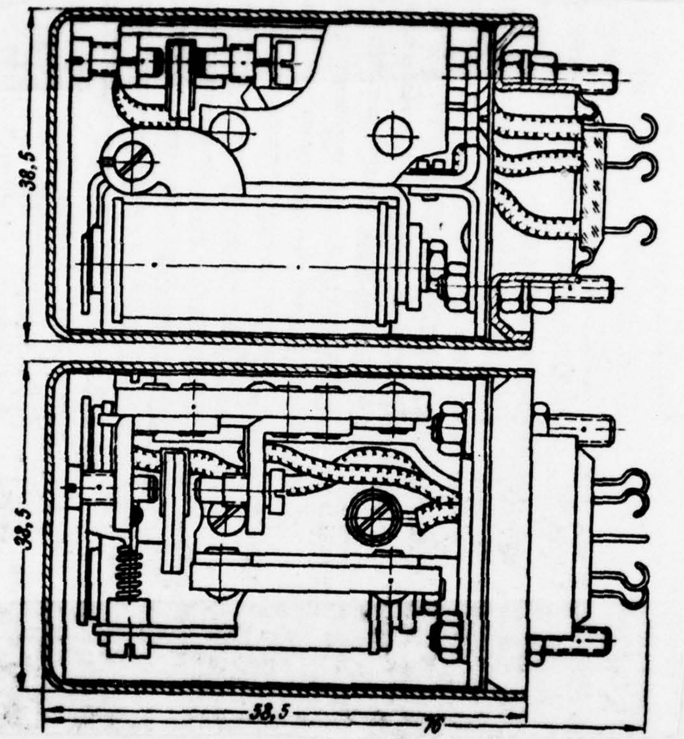

Fig. 1-10. Relays of the type RDChG.

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Nominal load of the contacts 0.4a-27v of direct current.

Service life of contacts with the resistive load of

10^5 cycles.

Insulation of the winding of relay maintain/withstands the testing voltage 1500 eff. V of alternating current, contacts, i.e., 500 eff. V.

Insulation resistance is not less than 5000 MΩ, after the stay under conditions of the increased humidity - it is not less than 100 MΩ. Overall dimensions of relay 40.1 x 40.1 x (50.5 + 16.5) mm, weight 180-220 g.

1-10. Miniature/small sealed relay of the type RES8.

A relay of the type RES8 with six stud switches is intended for operation in movable radio-electronic equipment and equipment for automation with the fluctuations of ambient temperature from -60 to +(90-125) °C, relative humidity to 98o/o at temperature of +40°C, atmospheric pressure to 5 mm Hg; vibration with frequency from 20 to 50 Hz and the amplitude of oscillations 1 mm, from 50 to 600 and acceleration 12g, from 600 to 800 Hz and acceleration 10g - from 800 to 1000 Hz and acceleration of 8g. from 1000 to 1500 Hz and acceleration of 5g and centrifigal (linear) acclerations to 50g.

Relay is maintain/withstood 1000 impacts with acceleration 50 g.

The general view of relay of the type RES8 is shown in Fig. 1-11. Relay has single-coil four-terminal magnetic system with symmetrical cross-shaped hinged armature. Cylindrical steel jacket (housing) serves as the magnetic circuit of relay. In the bottom of jacket, is sealed in the core with coil, the free end/lead of core is equipped by step bearing for the axis of armature. The second bearing is pressed into the base of relay. From inside of the jacket above the coil, are soldered four pole pieces in the form of corner irons.

Armature has a form of cross and consists of four plates, connected between themselves the hollow clutch into which is pressed the axis.

Magnetic flux from the core through the circular ballast air pole gap of core and the internal cylindrical surface of clutch enters in the armature where it branches on four parts and through four working air gaps falls into

the pole pieces (welded within jacket) and it is closed through the jacket of relay.

For the elimination of fluctuations during vibration, the armature of relay is held in initial position by two small permanent magnets, strengthened to the corner irons between the pole pieces.

Foundation (base) of relay made from Kovar alloy has a form of the cup intc bottcm of which are pressed the leading-out pins, isolate/insulated from foundation by insulating beads from the pressed glass.

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Relay has six the stud switches, positioned radially on the internal surface of foundation.

Fixed contacts from alloy ПлИ-10 are soldered to the internal end/leads of the leading-out pins, and movable - to the claws of contact spring.

Effort/force from armature is transmitted to movable contact springs with the aid of the mounted to armature

small cup from polyfluorcethylene resin, which has of six grooves (groove/slots) through which emerge the free end/leads of the movable contact springs. The small cup is equipped circular groove in which with friction can be turned copper ring (with cut/section). With the impact of the armature about of pole, the ring on inertia slips in groove and absorbs energy of impact.

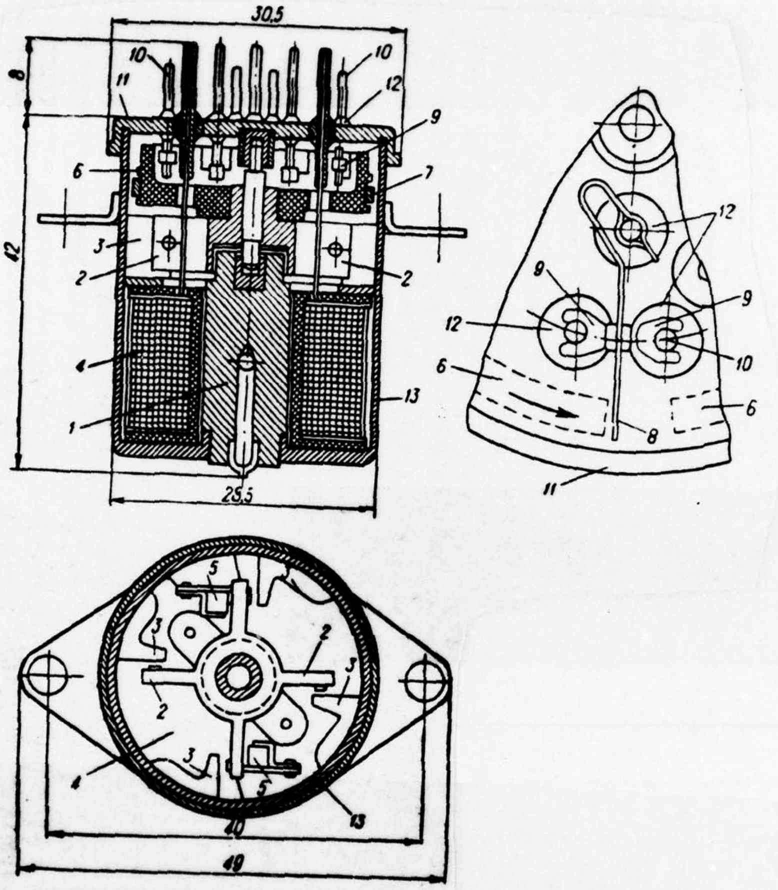

Fig. 1.11. Relays of the type RES8. 1 - core; 2 - armature; 3 - pole; 4 - coil; 5 - permanent magnet; 6 - driving/moving small cup from polyfluoroethylene resin; 7 - damping ring; 8 - movable contact spring; 9 - fixed contact; 10 - leading-out pin; 11 - socket of Kovar alloy;

12 - glass insulating bead; 13 - steel jacket.

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After assembly and adjustment, the foundation (base) is soldered to jacket. The internal volume of relay is evacuated, it is dried and is filled with the dry air through the stem, connected with channel in core.

Power of the function of relay 1.0-1.4 W.

Service life of contacts with resistive load 2a-30v - $2 \cdot 10^5$ functions, with resistive loads 0.3a-220v or 5 μA - 50 mV of direct current either 1a-50v alternating current by frequency 50-400 Hz $-3 \cdot 10^5$ of functions, with the resistive loads 5a-30v of direct current or 1a-115v alternating current $-5 \cdot 10^3$ of functions.

Insulation resistance is not less than 200 MΩ, after the stay under conditions of the increased humidity - 20 MΩ.

The testing voltage of insulation of relay 1000 eff. V

between the dead contacts 750 eff. V. Weight of relay 110 g.

1-11. Small relay of the type RES7.

A relay of the type RES7 with six stud switches is intended for operation approximately under the same conditions as relay of the type RES8 (with the exception of vibration in the range of frequencies from 600 to 1500 Hz with acceleration 5g and humidity 98o/o at temperature of +20°C).

The general view of relay of the type RES7 is given in Fig. 1.12.

Relay has single-coil two-pole magnetic system with symmetrical hinged armature. Magnetic system consists of the steel beaker within which is fastened the core with coil. In beaker are made two large grooves, which form the poles to which are attract/tightened the end/leads of the armature. Flat/plane symmetrical armature with the bent back downward end/leads is fastened on the vertical axis which is passed through the channel in core. Armature returns to initial position with two cylindrical springs.

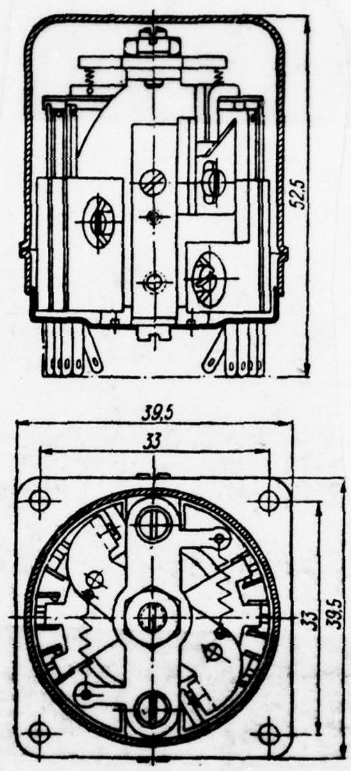

Fig. 1-12. Relays of the type RES7.

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To armature is riveted the plate from Textolite, which has in the circumference of six teeth for switching of contact springs.

Contact groups are arrange/located around the housing of relay in parallel to the axis of core. The average spring of each group rigid, and extreme are flexible.

Contacts have a form of hemisphere, they are made from alloy PlI-10. Pressure in contacts is not less than 7g. the gaps among the contacts of more than 0.25 mm.

Relays are closed by dustproof jacket from aluminum.

Power of the function of relay 0.8-1.2 W. Resetting ratio 0.14-0.2. Service life of the contacts $3 \cdot 10^5$ of functions with resistive load 2a-30v or 0.3a-300v of direct current and 1a-50v alternating current. Weight of relay 120 g.

1-12. Miniature relay of the type RES22.

Relay with four stud switches of the type RES22 is intended for operation at ambient temperatures from -60 to +85°C, relative humidity to 98o/o at temperature of +40°C, atmospheric pressure to 5 mm Hg, with vibration in the

range of frequencies from 20 to 50 Hz with amplitude 1 mm, from 50 to 200 Hz with acceleration to 10g, from 200 to 1500 Hz with acceleration to 3 g, linear accelerations to 15g. Impact strength 25g.

The general view of relay of the type RES22 is shown in Fig. 1-13.

Relay has valve type single-coil magnetic system with the core of rectangular cross section.

Armature asymmetric with two long levers on each side as in relay of the type RMU.

Package type two contact groups with flat/plane contact springs and fiberglass laminate separators are tightened by one common/general/total screw/propeller. Each group consists of six contact springs. Motionless springs lie/rest on supporting springs, the end/leads of the movable springs rest on the driving/moving framework from glass-fiber laminate, strengthened to the end/leads of the levers of armature. The end/leads of the motionless springs are bisected and equipped by dual silver contacts.

Relay has the rear fender made of steel and shielded detachable aluminum jacket which is held by the wire steel spring having U-shaped form.

Pressure in contacts is not less than 10g the gaps among the contacts of more than 0.3 mm.

Power of the function of relay 0.23-0.28 W. Resetting ratio 0.2-0.24.

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Service life of the contacts of relay with resistive load 2a-30v and 0.3a-220v of direct current or 0.3a-115v and 0.1a-220v alternating current (50-1000 Hz) - 10^5 cycles; with load 3a-30v - 10^4 cycles; with load 1a-30v - $3 \cdot 10^5$ cycles; with load 0.1a-300v - $5 \cdot 10^5$ cycles; with load 0.3a-60v - 10^6 cycles and with load 0.05a-60v - 10^7 cycles. Contact resistance to tests for service life is not more than 0.6 ohm.

Triggering time of relay is not more than 12 ms, releasing time is not more than 5 ms.

The capacitance/capacity of contact system is not more than 5 pF.

The insulation resistance of relay is not less than 100 MΩ, in conditions of increased humidity of more than 10 MΩ.

The testing voltage of insulation of winding and contacts 500 v, under conditions of increased humidity - 250 v.

The weight of relay is not more than 36 g.

1-13. Miniature relay of the type RES6.

A relay of the type RES6 is a miniature relay with two stud switches, intended for operation in movable miniature/small equipment with variations of the temperature of surrounding air from -60 to +85°C; the increased humidity to 98o/o at 20°C, vibrations with frequency from 15 to 1500 Hz and by acceleration to 6 g, linear accelerations to 25 g and atmospheric pressure to 5 mm Hg. Relay is maintain/withstood 1000 impacts with acceleration 50 g.

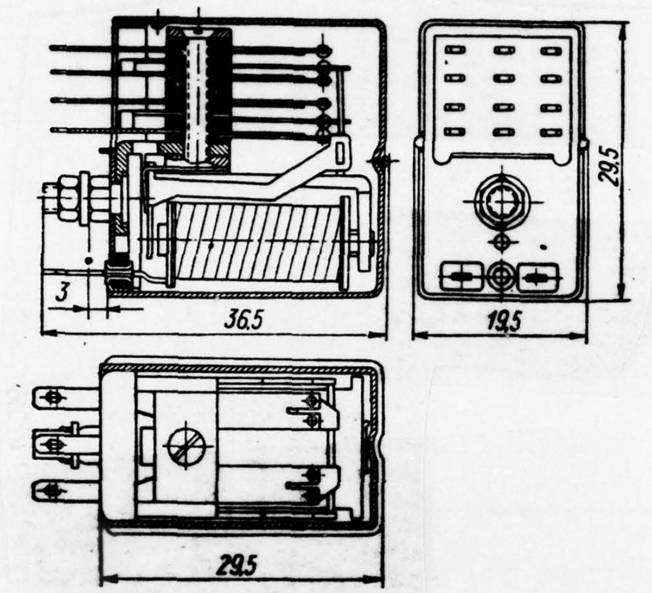

Fig. 1-13. Relays of the type RES22.

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The general view of relay of the type RES6 is shown in Fig. 1-14.

The magnetic system of relay of the type RES6 is analogous to the magnetic system of relay of the type RSM, but the length of core and housings is somewhat more (22 mm).

Contact system has another construction; contact springs with separators of fiberglass laminate are assembled into the packet which with two screw/propellers is fastened to housing. All springs are made from bronze by thickness 0.15 mm.

Motionless springs lie/rest on brass supporting springs. Length of contact springs 14.5 mm, width 4 mm. Contacts dual, silver.

The contacts of winding are derived to soldering plugs (lug/lobes), placed into contact packet.

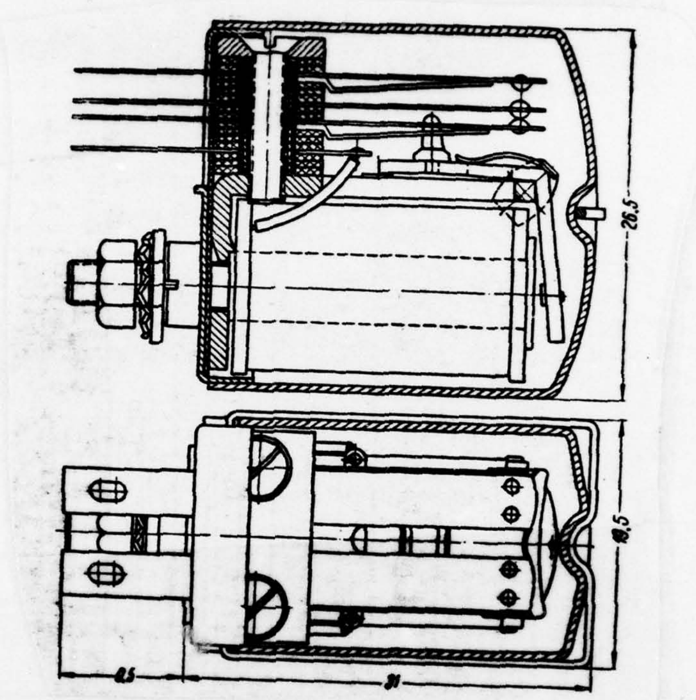

Fig. 1-14. Relays of the type RES6.

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The contacts of relay are maintain/withstood with the resistive loads: 0.3a-30v the direct current of 10^6 cycles, 1a-30v - $3 \cdot 10^5$ cycles, 2a-30v - $1.5 \cdot 10^5$ cycles, 3a-30v - 10^4 cycles, 6a-28v - $5 \cdot 10^3$ cycles, 0.1a-300v - $5 \cdot 10^5$

cycles, 0.3a-250v - $2.5 \cdot 10^5$ cycles and 1a-115v alternating current - $5 \cdot 10^4$ cycles.

Power of the functicn of relay 0.5-0.8 W.

Insulation resistance 100 MΩ, after the stay under conditions of the increased humidity for 48 h - 10 MΩ. The testing voltage of insulation of winding and contacts 500 eff. V.

Relay has the rear fender made of steel and it is shielded by detachable aluminum jacket which is held by U-shaped spring from steel wire.

1-14. Miniature relay of the type RES9.

A relay of the type RES9 with two switching contacts is designed for operation at the temperature of that surrounding air from -60 to +85°C; relative humidity to 98o/o at +40°C; vibration in the range of frequencies from 20 to 50 Hz from amplitude in 1 mm and from 50 to 600 Hz with acceleration to 12g, linear accelerations to 25g

and atmospheric pressure to 5 mm Hg. Relay is maintain/withstood 1000 impacts with acceleration 50g.

Fixed contacts have cylindrical form, they are welded to the internal end/faces of the leading-out pins, pressed into the base of relay.

Contacts are manufactured from silver and alloy PlI-10.

The general view of relay of the type RES9 is shown in Fig. 1-15.

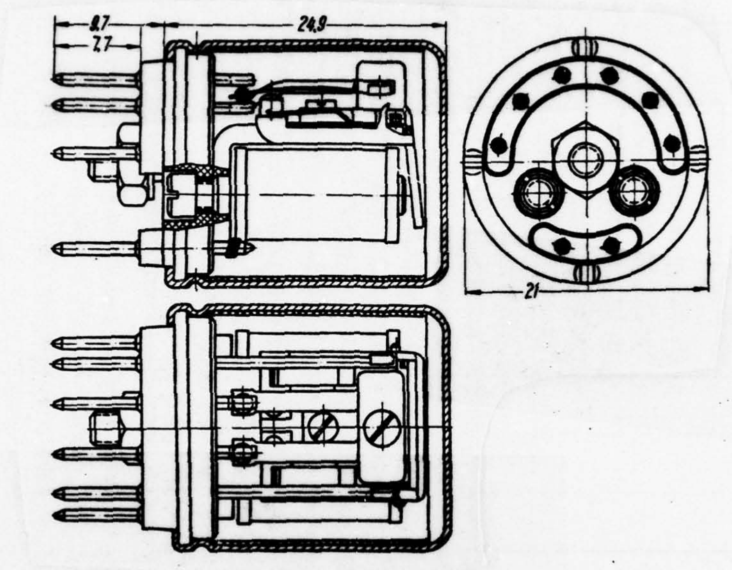

Fig. 1-15. **Relays of type RES9.**

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The magnetic system of relay is two-coil of the valve type. Diameter of cores 3.5 mm, length 15 mm; the thickness of housing 1.5 mm, width 10 mm. Armature is suspend/hung on the axis and has on each side two elongated levers with the insulating bushes at end/leads. The course of the armature of relay 0.3 mm, of plug there is no loosening.

Pressure in breaking contact by 8-10 g. The gap among contacts is more than 0.3 mm. Pressure of return springs 2 x 8 g.

Slide contacts are riveted to movable contact springs, pressed by one end/lead into the plastic block, strengthened to the housing of relay. The working length of movable springs 10 mm, width 2 mm thickness 0.15 mm. The spherical surface of slide contact concerns the lateral cylindrical surface of fixed contact. Length of the fixed contact 2 mm, diameter 0.95 mm. Diameter of the slide contacts 1.5 mm, height 0.4 mm.

The jaws of coils are made from fiberglass laminate. Winding is isolate/insulated about core by three layers of teflon tape by thickness 0.02 mm. Inner diameter of the winding 3.7 mm, length 1 mm height 1.6-1.8 mm.

Winding is made from the heat-resistant enamelled wire of the brand PETV.

Great winding impedance 9600 ohm (d = 0.03 mm), minimum

spill current 7 mA. Relay reset coefficient 0.25-0.45.

The base of relay has circular shape and it is pressed from heat-resistant plastic.

In the base of relay, it is pressed in circumference eight of leading-out pins from white copper by diameter 0.95 mm for the inclusion into printed circuit with subsequent soldering.

In the center of the base is establish/installed the screw/propeller for the attachment of relay. Relay are protected by the cylindrical aluminum jacket whose edge is rolled on the basis.

The service life of silver contacts with resistive load 2a-30v - $1.5\cdot10^5$ cycles ~~qiklov,~~ of ~~pri~~ 0.3a-250v of direct current is not less $3\cdot10^5$ cycles, with the load 0.2a-115v of alternating current (50 Hz) or 0.5a-115v (1100 Hz) it is not less than 10^5 cycles. The service life of contacts of alloy ØlI-10 with the resistive load 0.8a-30v of direct current is not less $8\cdot10^5$ cycles.

The power, consumed by relay during function, is

0.46-0.51 W. Triggering time with nominal voltage is not more than 5 ms, releasing time is not more than 3 ms.

Insulation of winding and contacts maintain/withstands testing voltage 500 eff. V. Insulation resistance 100 MΩ. Weight of relay 20 g.

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1-15. Miniature relay of the type RES10.

A relay of the type RES10 is a miniature relay with one stud switch, designed for operation in movable equipment.

Relay has the dustproof aluminum jacket, rolled in on the basis.

Overall dimensions 10.6 x 16 x (19 +6.8) mm, weight 7.5 g.

The general view of relay of the type RES10 is shown

in Fig. 1-16.

The magnetic system of relay is single-coil of the valve type.

Diameter of core 3 mm, length 11 mm. the diameter of the pole piece 4.5 mm. Width of housing 8.5 mm, thickness 1.2 mm.

Armature is record/fixed on housing by two lugs of the special bracket, riveted to housing, and it is held by two return springs from beryllium bronze. Thickness of armature 0.7 mm.

Core and housing are fastened with the aid of the circular nut to base from heat-resistant plastic. Coil form is pressed out from that of plastic. Winding is made from the heat-resistant wire of the brand PETV and it is shielded outside by tape from polyfluoroethylene resin. Inner diameter of the winding 3.5 mm, length its 8.9 mm, height 1.8-2.2 mm. Fixed contacts have cylindrical form, they are welded to the internal end/faces of the leading-out pins, pressed into the base of relay. Slide contact is fastened on the movable contact spring, riveted to the armature of

relay and by the connected with housing fine/thin bronze ribbon. Contact spring is made from beryllium bronze; the working length of spring 5.3 mm, width 2.5 mm thickness 0.15 mm. Diameter of slide contact 1.5 mm, of motionless 0.8 mm. the material of contacts ρlI-10.

The base of the relay is pressed five of leading-out pins for the inclusion into printed circuit.

The course of the armature of relay 0.3-0.4 mm, of plug there is no loosening. Gap between the contacts 0.15-0.2 mm; pressure in contacts 7-12 g Pressure of return springs 17-25 g , Freewheeling escapement is more than 0.1 mm.

Power, consumed by relay during function, 0.29-0.34 W (with the circuit closing contact 0.16-0.18 W).

Great winding impedance 4500 ohm (d = 0.03 mm); minimum spill current with the circuit closing contact 6 mA and with the stud switch 8 mA. Relay reset coefficient 0.12-0.40.

The contacts of relay are maintain/withstood 10^5 cycles

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)
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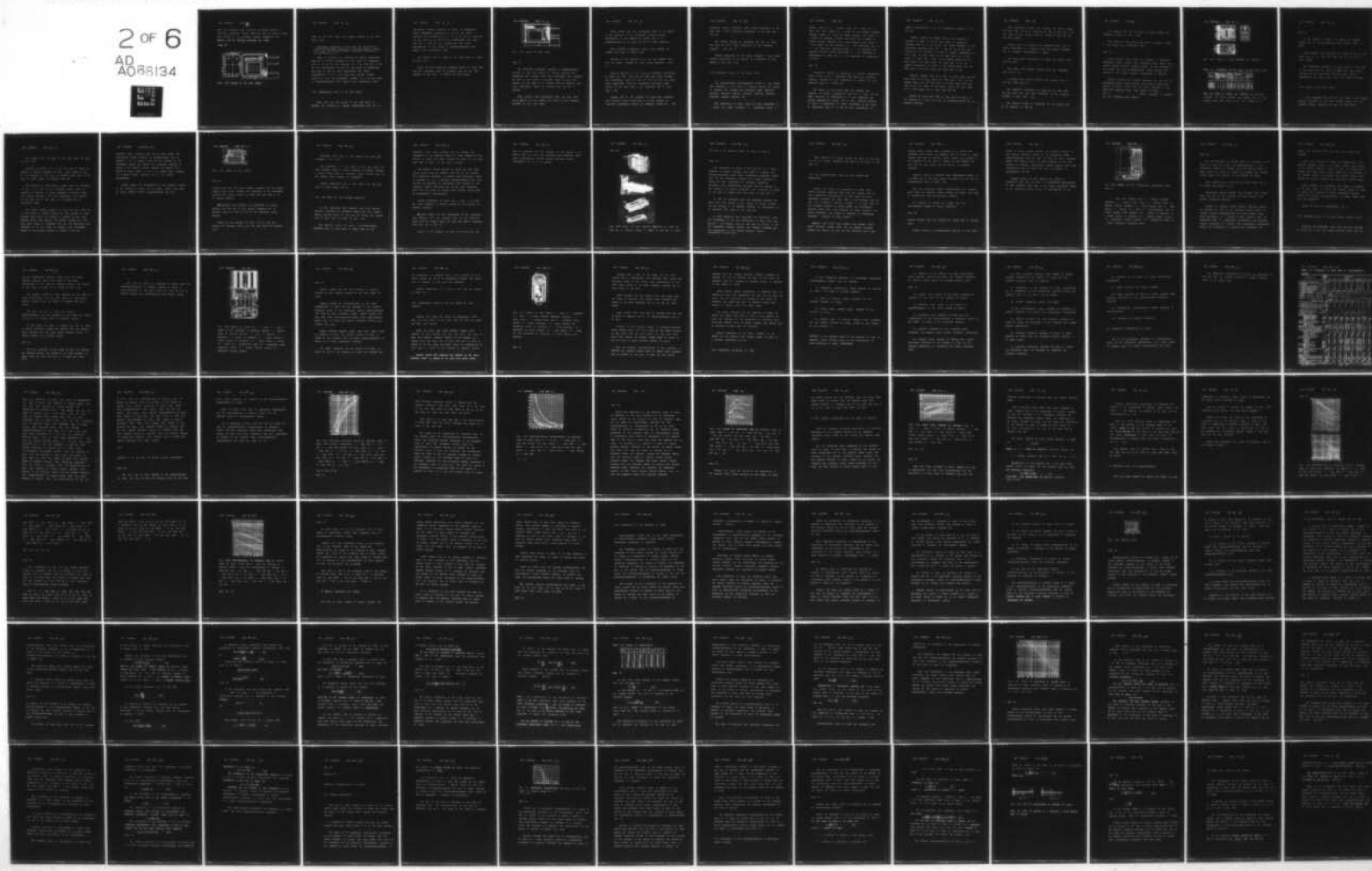

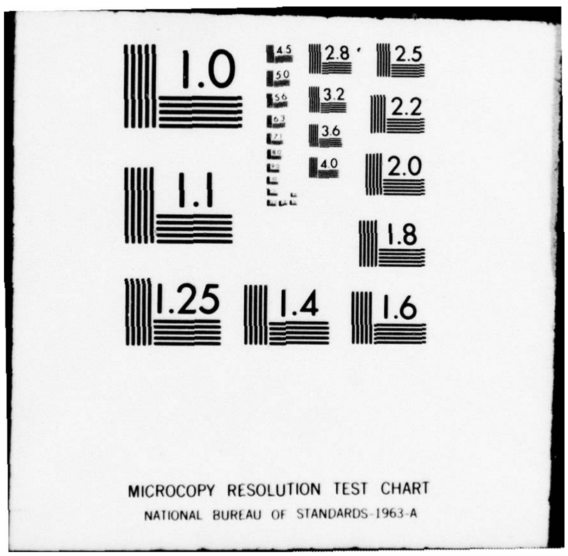
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MICROCOPY RESOLUTION TEST CHART
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with the resistive load 0.3a-250v of direct current or 0.5a-115v alternating current (50-1100 Hz) and $2.5 \cdot 10^4$ cycles with 2a-30v. At the increased ambient temperature the service life of contacts decreases two times.

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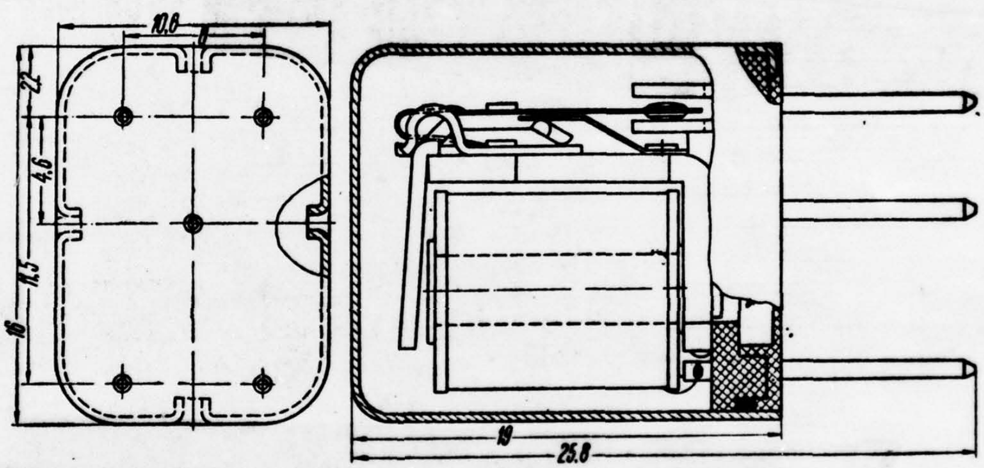

Fig. 1-16. Relays of the type RES10.

Page 40. The time delay with nominal voltage is not more than 8 ms.

Insulation resistance is more than 100 MΩ, after 48 hours of holding under conditions of increased humidity, greater than 10 MΩ. The testing voltage of insulation of winding and contacts 500 eff. V.

Relay is intended fcr operation at ambient temperature from 60 to +100°C; vibration in the range of frequencies from 20 to 50 Hz with amplitude to 1 mm, from 50 to 600 Hz with acceleration 12g and in the range of frequencies from 600 to 1500 Hz with acceleration 5g; linear accelerations to 80 g (of relay with circuit closing contact to 25g) and atmospheric pressure to 5 mm Hg. Relay is maintain/withstood 1000 impacts with acceleration 100g.

1-16. Subminiature relay of the type RES15.

Relay with one stud switch of the type RES15 is intended for operation at ambient temperatures from -60 to

+(85-100)°C, relative humidity to 98o/o, to temperature +40°C, atmospheric pressure to 5 mm Hg (at +60°C), vibration with frequency from 5 to 50 Hz and to amplitude 1.5 mm, from 50 to 600 Hz and acceleration 15g, also, from 600 to 1000 Hz and acceleration 10g, linear accelerations to 25g. Relay is maintain/withstood 2000 impacts with acceleration 100g.

The general view of relay of the type RES15 is given in Fig. 1-17.

Relay has the single-coil magnetic system of valve type with the flat/plane core of L-shaped form. To the long end/lead of the core, is welded the pole piece.

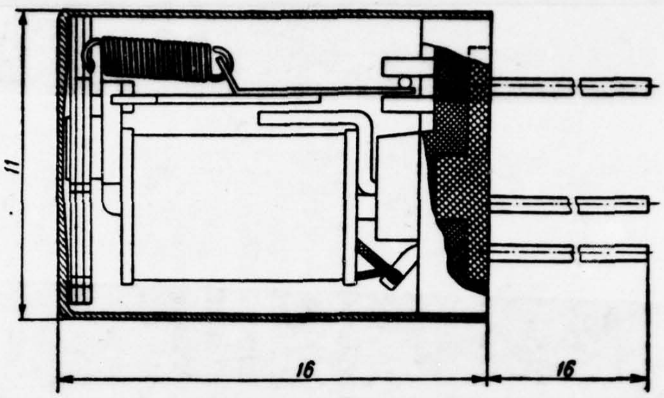

Fig. 1-17. Relays of type RES15.

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The flat/plane unbalanced armature is arrange/located parallel to core and returns to initial position with cylindrical hair spring. Coil form, detachable from plastic,. The base of the relay of circular shape is made from plastic. In the base it is pressed five of flexible lead wires (end/leads), three for contacts even two for a winding.

Fixed contacts have cylindrical form, are made from alloys ПлИ-10 and are welded into joint to the internal end/leads of two lead wires.

Slide contact has also cylindrical form: it is welded to the end/leads of the flat/plane U-shaped spring, strengthened to the armature of relay, and it is arrange/located at an angle of 90° to fixed contacts.

Relay shielded cylindrical jacket from aluminum is flooded from base by epoxy resin.

Pressure in the contacts 3 g, the gap between them - 0.15 mm. Power, consumed by relay during function - 0.15 W.

Winding impedance of the relay of different certificates is equal to: 160, 330, 720 and 2200 ohm. spill currents are respectively equal to: 30; 21; 14.5 and 8.5 mA. Relay reset coefficient 0.23-0.24. Triggering time with rated current is not more than 8 ms, releasing time is less than 2 ms.

Service life of the contacts of relay with resistive load 0.2a-30c either 0.015a-150c of direct current or 0.13a-127c alternating current by frequency 50-400 Hz - 10^5

functions. Contact resistance under normal conditions is not more than 1 ohm. Insulation resistance is not less than 100 MΩ.

The testing voltage of insulation 500 eff. V, after the stay for 48 h under conditions of the increased humidity - 250 eff. V.

Overall dimensions of the relay: diameter 11 mm, length without conclusions 16 mm (length of conclusions 16 mm). Weight is not more 3.2d.

1-17. Miniature relays of the series TKYe.

The miniature/small electromagnetic relays of the series TKYe depending on the value of commuted current and number of contacts are released the following types: TKYe210B, TKYe21PD, TNYe21PD, TKD21PK, TKYe52PD, TKYe53PD, TKYe53PK, TKYe56PD, TKD12PD, TKD12PK, etc.

The designation of these types of relay designates: T - thirty volt (great voltage); K - commutation relay, N -

voltage relay or T - current relay; Ye - units or D - tens; the first numeral is a value of the nominal switched amperage (number of unity or dozens ampere); the second is a number of breaking contact; the third is a number of circuit closing contacts; the second numeral with letter P - the number of stud switches; D - the continuous duty or K - the short-term operating mode; U - is specified the actuation voltage during vibrations; O - for operation at temperatures to +60°C and T - for operation at temperature to +90°C.

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Designation TKD12PD is deciphered as follows: commutation relay on 30 v for a continuous duty with two switching contacts, designed for the commutation of current 10a with inductive load (τ = 0.015 s).

The relays of the series TKYe are intended for operation at ambient temperatures from -60 to +50°C (if the upper apparitor of temperature it is not stipulated by special supplementary letter "O" or "T"), relative humidity to 98o/o at temperature of +20°C, vibrations in the range of frequencies from 10 to 200 Hz with acceleration 5g,

linear accelerations to 8g and atmospheric pressure to 41 mm Hg.

Nominal voltage on winding and in the circuit of contacts is equal to 27 V, the limits cf operating stresses from 24 to 30 V (for the relay, designed to the short-term operating mode "K" - from 16 to 30 V). The voltage of the function of relay at ambient temperature of 20 ± 5°C; in cold state is not more than 14 V (for relay "K" less than 9 V), in the heated state are not more than 18 V (for relay "K" less than 12 V); at ambient temperature of +50°C in the heated state are not more than 22 V (for relay "K" less than 14 V).

Drop-out voltage with 20 ± 5°C: in cold state are not more than 3.5 V (for relay "K" less than 2 V), in the heated state are not more than 5 V (for relay "K" less than 3 V); at +50°C in the heated state, not more than 5.5 V (for relay "K" is less than 3.5 V).

During the short-term mode of the work of relay, it is included on 5 min, and then is disconnect/turned off to complete cooling.

With alternating current the contacts can switch voltage not more than 220 V at frequency to 900 Hz and cos $\phi \geqslant$ 0.5 (load of all contacts must be connected from one and the same phase).

Service life of contacts with inductive load - 10^4 of cycles (functions). At resistive load the current strength can be increased approximately to 60o/o.

The relay reset coefficient is within the limits from 0.09 to 0.15.

Time delay with nominal voltage 10-14 ms, releasing time 2.4-3.5 ms.

A voltage drop across contacts with nominal load is not more than 0.09 V.

The insulation resistance of relay is not less than 100 MΩ, after the stay under conditions of the increased humidity of more than 3 MΩ.

The testing voltage of insulation of the winding 500 V, of contacts is 1500 V.

The general view of the relay of types TKE21PD and TKYe21PK is shown in Fig. 1-18.

The relays of the series TKYe have a magnetic system of the valve type of Sh-shaped form.

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Fixed contacts from silver are soldered to flat/plane leading-out buses, pressed into insulating panel (base) from plastic (brand K-21-22). Magnetic system is also fastened to this panel with two screw/propellers. Slide contacts are riveted to the contact spring, strengthened to armature.

Armature returns with initial position with the aid of cylindrical spiral return spring. Coil form is made from plastic of brand K-21-22 (for the relay, designed to the short-term operating mode, from plastic of brand FKP-1. Jacket (cap/hood) is stamped out from aluminum alloy AMtsA-M.

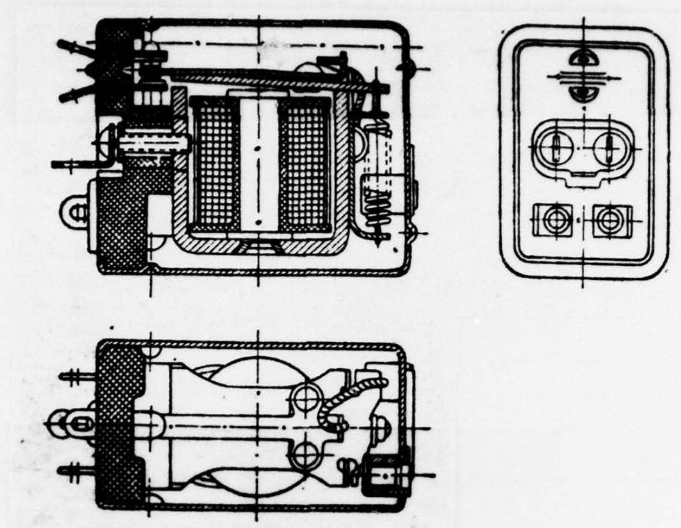

Fig. 1-18. Relays of types TKYe21PD and TKYe21PK.

Table 1-1. Parameters of the relay of the series TKYe.

(1) Тип реле	(2) Количество переключающих контактов	(3) Номинальный ток $I_н$, а	(4) Мощность		(6) Габарит			(7) Объем V, см³	(8) Вес Q, г
			(5) $P_с$, вт	(5) $P_н$, вт	B, мм	L, мм	H + h, мм		
ТКЕ21ПД	1	2	0,5	2,5	19	29	40 + 4,5	24,6	35
ТКЕ52ПД	2	5	0,8	4,0	27	42	45 + 7	59,0	90
ТКЕ53ПД	3	5	0,9	4,6	33	42	51 + 7	80,6	120
ТКЕ56ПД	6	5	1,3	6,0	45	48	58 + 7	140	240
ТКД12ПД	2	10	1,0	5,8	40	48	62 + 8	134	220

Key: (1). Type of relay. (2). Quantity of switching contacts. (3). Rated current. (4). Power. (5). W. (6). Overall size. (7). Space V, cm³. (8). Weight Q, g.

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In the bottom of jacket, are rolled two screwed sleeves for the screw/propellers, which fasten relays to board.

After assembly and adjustment on relay, is put on the jacket and of its edge they open out on the edge of panel (base).

The fundamental parameters of some types of the relay of the series TKY are given in Table 1-1. The relays, intended for the short-term operating mode, consume approximately two times large power with nominal voltage.

1-18. Relays of the type RES14.

A new telephone relay of the type RES14 to 24 contact springs, developed by the plant "Tesla" (CSSR), has the magnetic system, analogous to relay of type RKM-1.

The general view of relay of the type RES14 is shown in Fig. 1-19.

Section of housing 22 x 2 mm. The core of relay is welded to housing. Diameter of core 7 mm, length 60 mm. To the end/lead of the core, is mounted polar shoe in the form of steel washer by diameter 15/7 mm.

The armature is made made of sheet steel by thickness 1.5 mm, it is held by the flat/plane plate, welded to housing. To armature is stuck nonmagnetic antistick strip from plastic material. Coil form detachable, from plastic. In the rear jaw of the coil it is pressed six of leading-out plugs.

The contact system (packet) of relay can have from two to six series of contact springs in four springs in each, moreover each series of springs is pressed of base into separate block from plastic. The movable springs are made from white copper as thickness 0.35 mm, and motionless have thickness of 0.5 mm. Width of springs 3 mm, calculated length 40 mm. Movable springs at length 17 mm are

bisected, their end/leads bent and to them welded the longitudinal silver contacts of semicylindrical form by diameter 1 mm by length 2 mm. To the end/lead of the motionless springs are welded the transverse contacts by length 3 mm. Movable contact springs are pressed into blocks at small angle, so as to to ensure after assembly the assigned contact pressure (20 ± 2 g) without readjustment.

Contact packet is collect/built in the cassette, welded to the housing of relay, and it traces itself from above by spring bracket without screw/propellers and nuts.

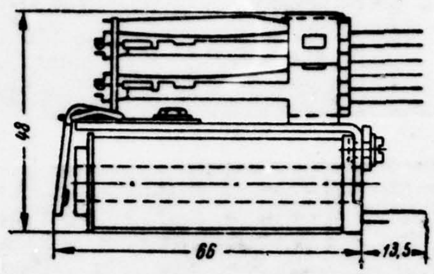

Fig. 1-19. Relays of type RES14.

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Cassette has from two sides stepped supports for the second plastic block which fastened the end/leads of the motionless springs. The contact system of relay can have from 4 to 24 contact springs.

Effort/force from armature is transmitted to contact springs with the aid of the special framework out of getinax, which is held on top by two flat/plane return springs.

Course of the armature of relay 1.5 mm; the gap between the contacts 0.4-0.5 mm; the gear ratio of armature 0.72.

Time-lags relay have on core copper tube with wall thickness 1 or 2 mm.

The advantages of a new relay of the type RES14 are small overall sizes, a larger quantity of contact springs, a little higher speed of response, larger service life and the smaller labor expense of adjustment.

Overall dimensions: 22.7 x 48.5 (39) x 80 (66) mm, space 88 cm³, weight 170 g.

1-19. The relay of firm "Western Electric"

In 1952 laboratory Bell together with firm "Western Electric" developed new telephone relay with wire contact springs (string relay) of the type AF [1-25]. The general view of this relay is shown in Fig. 1-20.

The magnetic circuit of relay - die-forge/stamped, Sh-shaped form; is made made of sheet steel by the

thickness 4 mm, which provides 1o/c of silicon. The reluctance of the magnetic system of relay because of the absence of joint and larger surface of poles is 2.3 times less than in relay of the type U [1-19].

The movable contact springs of relay are made from German silver wire by diameter 0.58 mm and are pressed into comb/racks (packets) of plastic (one flat/plane spring is replaced by two in parallel arranged/located wires with contacts of palladium on end/leads). Wire springs do not virtually require adjustment and dc not give vibration, since for the break of circuit both contacts vapors must be disconnectted simultaneously.

Overall dimensions of relay 48.4 x 37.2 x 115 (96) mm. Great quantity of contact springs 48 (24 closing or breaking contact).

Specific volume 8.7 cm^3. Sensitivity 12 mW. Triggering time composes 2.7-5 ms, releasing time 2-7 ms. Time-lags relay with red copper tubes (of type AG) have a releasing time from 200 to 530 ms.

Course of the armature of relay 0.7-1.1-1.5 mm, the

plug of loosening 0.15 mm. Pressure in the contacts 6 g. Service life of relay with inductive load 0.09a-60c (with spark extinguishing) 250-500 million functions without readjustment (of up to 40 years).

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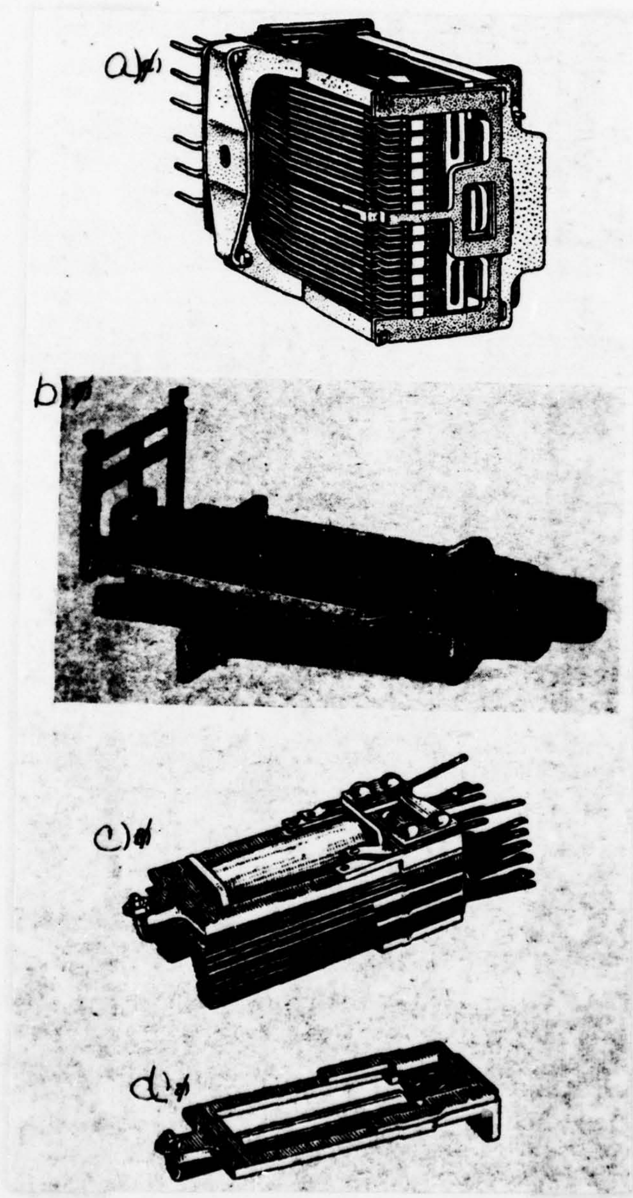

Fig. 1-20. Relays of firm "Western Electric": a) relay of type AF; b) magnetic system of relay of type AF; c) relay

of type U; d) magnetic system of relay of type U.

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The advantages of relay of the type AF is a large quantity of contact springs, high speed of response and release/temperings, small power consumption, prolonged service life and low cost/value. Because of a small quantity of parts, the wide application of automatic production processes, high manufacturing precision and the absence of the necessity for manual adjustment, the cost/value of relay of the type AF almost half than relay of the type U.

In 1954 in laboratory Bell was develcped multiple arm relay with wire springs [1-26], having 60 contact springs (30 the closing or 30 breaking contact). By construction it is analogous with relay of the type AF.

In 1958 laboratory Bell published the information about the development of the new modification of relay with wire springs - the doubled relay of the type AK [1-27]. It has two independent magnetic systems with separate windings and the dialing/sets of the contact springs, working independently of each other.

Total quantity of contact springs of relay of the type AK and its overall dimensions the same as in relay of the type AF.

1-20. The miniature/small relay of firm "Electro-Tek Corporation".

Figures 1-21 shows the cut/section of relay with suction armature (solenoid type) and the conical stop of firm "Electro-Tek Corporation". Of this relay the core (ream/feet) occupies the lower half of the internal duct of coil, and cylindrical armature (plunger) - an upper part of this channel. Armature is moved within the thin-walled directing brass tube. For provision by large vibration- and impact resistance, the weight of armature is considerably decreased - armature is made hollow.

Magnetic flux falls into plunger from passage collar (which surrounds plunger steel tube of magnetic circuit) through the ballast air gap and the directing brass tube.

Passage collar (steel tube) concludes in a bottom that surrounds coil outside the magnetic flux of relay is closed through the edge of end-type collar (steel jaw, mounted to the end/lead of the core of relay) and the working air pole gap of core (stop) and the bottom of armature (plunger).

Magnetic system is soldered with high-melting solder or is welded on to the base (base) of relay with the aid of framework/body made of sheet iron.

Coil has relatively larger size/dimensions and occupies about 70o/o of internal volume (length) of relay. Coil form is manufactured from heat-resistant plastic.

For windings is applied red copper wire with heat-resistant enamel or teflon insulation.

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Outside winding they are shielded by teflon tape or polymer film.

Contact system is arrange/located directly on the basis

(base) of relay. Contact springs are soldered directly to the internal end/leads (pins) of the leading-out hooks, isolate/insulated from the base of relay by glass insulating beads. The contact system of relay consists of six stud switches of original construction. Contact springs have round cross-section and are made from wire by diameter of approximately 0.8 mm.

Movable springs by one end/lead are welded to leading-out pins and are bent in circumference approximately to 400° (somewhat more than to one turn). Calculated length of the rectified movable spring of approximately 21 mm.

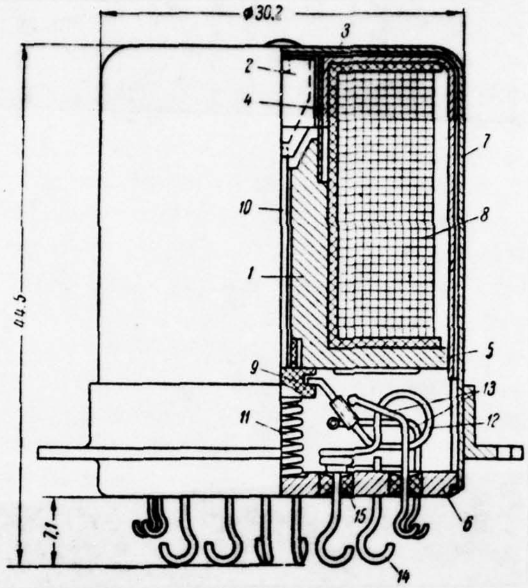

Fig. 1-21. Relays of firm "Electro-Tek Corporation" type Mark II.

1 - core with conical stop; 2 - suction armature (plunger); 3 - guiding brass tube; 4 - passage collar of magnetic circuit (beaker); 5 - steel closing jaw; 6 - base (base); 7 - jacket; 8 - coil; 9 - driving/homing bush of contact system (from plastic); 10 - pusher of armature; 11 - return spring of armature; 12 - movable contact spring; 13 - motionless contact springs; 14 - leading-out hook; 15 - glass insulating insulating bead.

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The free end/lead of movable spring is directed to the center of relay and enters in opening/aperture on the cylindrical surface of stepped bush from plastic which is moved under the action of pusher and changes over contact groups during the function of the plunger of relay.

Slide contact has a form of the short tube, put on to spring and welded to it.

"Motionless" contact springs have L-shaped form, length their 4-6 mm. To the end/leads of these springs, are welded cylindrical contacts.

Pressure in normally closed contacts increases because of pressure the bush of the recurrent helical spring of plunger. During closing/shorting the slide contact slips along motionless, as a result of which contacts they fit themselves well, is remove/taken contamination and decreases contact resistance of contacts. This construction considerably raises the reliability of contacts with vibrations and

impacts and improves their work with low currents and voltages.

During the function of relay, the effort/force from armature (plunger) through the tubular pusher, which passes in the through channel, drilled in core, is transmitted to stepped bush from plastic which presses on the end/leads of the movable springs and changes over contact groups. Bush returns to initial position with cylindrical spiral spring.

After assembly and adjustment, the jacket is soldered to the base (base) of relay. The internal volume of relay is filled with nitrogen at normal atmospheric pressure through the special opening/apertures in jacket, which then also are solderred.

Weight of relay of approximately 130 g.

1-21. Miniature relay of the firm "Elgin National Watch"

Miniature electromagnetic relay with two stud switches of series MV of the firm "Elgin National Watch" has the

two-coil nonpolarized magnetic system with the rotary balanced armature, which are turned on the axis, side-by-side to the cores of magnetic circuit. The outline of the relay of series MV is given in Fig. 1-22.

The magnetic system of relay consists of two cores of round cross-section with the pole pieces of semicircular section, pressed into the clamp of U-shaped form from brass.

To cores are put on coils with plastic framework/bodies, and the end/leads of the cores are rolled on top in the closing plate of magnetic circuit.

In the middle of clamp, is pressed the axis on which is turned flat/plane symmetrical armature with two pushers, which conclude with the glass beads. Armature returns to initial position with helical spring.

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The free end/leads of the clamp on which is fastened the magnetic system, are welded to the base (socket) of relay. base has oval form and it is made from Kovar alloy.

Both coils of relay are connected in series. Upon the connection/inclusion of armature winding, of relay is attract/tightened to the pole pieces and with the aid of pushers changes over simultaneously both contact groups.

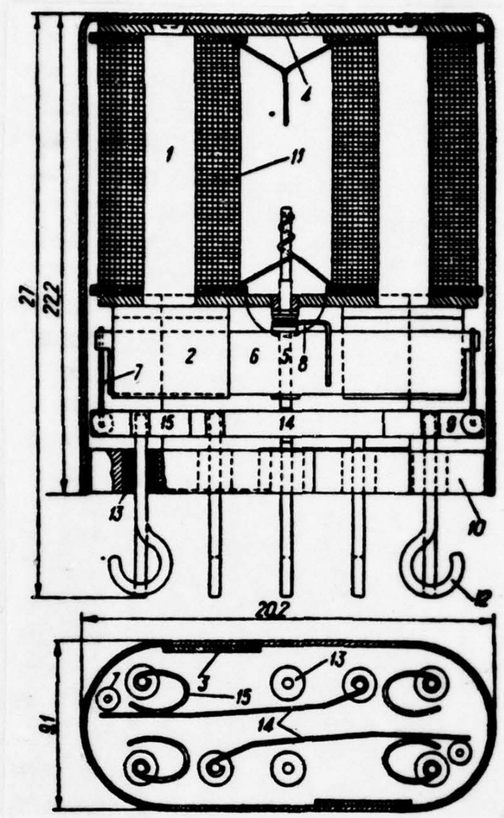

Fig. 1-22. Relays of series MV. 1 - core; 2 - pole, 3 - clamp of the attachment of magnetic system; 4 - closing plate of magnetic circuit; 5 - axis of armature; 6 - armature; 7 - pusher of armature; 8 - return spring; 9 - travel limiter of armature; 10 - socket (base of relay); 11 - coil; 12 - leading-out hook; 13 - insulating glass insulating beads; 14 - movable contact spring; 15 - motionless contact spring.

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Contact system with two stud switches is mounted directly on the internal surface of the base (base) of relay.

Contact springs are arrange/located in the plane, perpendicular to base, and are soldered to the internal end/leads (pins) of the leading-out hooks, isolate/insulated from base by glass insulating beads. Contact springs are made from alloy silver-magnesium-nickel which simultaneously serves both as spring and contact material. Contacts are covered with gold.

Relays shielded seamless jacket from white copper which is soldered to base. The internal volume of relay is filled by dry nitrogen with the small impurity/admixture of helium at a normal atmospheric pressure.

The power, necessary for the function of relay, is equal to 0.25 W. The contacts of relay are intended for

the commutation of resistive load a with voltage 32 V of direct current or 115 V of alternating current. The service life of contacts is more than 10^5 functions.

Overall dimensions: 9.1 x 20.2 x 22.2 (27) mm. Weight is about 14 g.

1-22. Subminiature relay of firm "S. Smith and Sons, Limited".

Figures 1-23 shows the device of subminiature relay with one stud switch of the type 11PCR of firm "S. Smith and Sons, Ltd" [1-27].

Relay has armor type valve magnetic system, which consists of iron cylinder and core with coil. Coil form is made from plastic. Flexible outputs of the winding are pressed into the lower jaw of coil. The pole of core is sealed in in the brass jaw which after the winding/coil of coil seals in itself in the cylinder of magnetic circuit.

Contact system and armature are mounted on the glass insulator which is sealed in in ring from Kovar alloy.

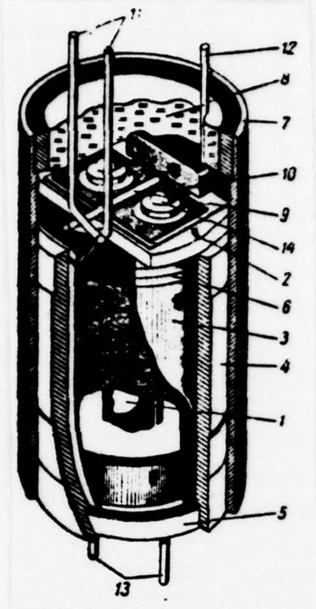

Fig. 1-23. Relays of type 11PCR. 1 - core; 2 - armature; 3 - coil; 4 - steel cylinder (magnetic circuit); 5 - steel base; 6 - sealing brass jaw; 7 - external brass jacket; 8 - glass insulator; 9 - slide contact; 10 - suspension spring of armature; 11 - fixed contacts; 12 - conclusion of slide contact; 13 - coil leads; 14 - rivet for the attachment of insulation of slide contact from armature.

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Armature has a form of the plate, cut out from circle, and is suspend/hung from fine/thin flat spring from beryllium bronze to the corner iron, strengthened to two lead wires, sealed in in glass insulator (outside one of these wires is cut off).

Fixed contacts are two covered with gold wires from the alloy of platinum with rhodium whose end/leads are sealed in in glass insulator and it is bent at right angles.

Slide contact also from wire is fastened with the aid of clamp at armature and it is isolate/insulated from it by mica.

Pressure in the breaking contact is establish/installed within limits from 7 to 15 g, but the gap among contacts is more than 0.076 mm, after which the ring from Kovar alloy with contact and movable system seals in itself on the one hand in brass cylinder (jacket of relay).

Into the opposite opening/aperture of this cylinder, is inserted the magnetic system which is moved, while armature will be pullled to the pole of core and will switch

contacts with the minimum actuation voltage, conducted to winding. By this is provided the unit of the course of armature. Then the cylinder of magnetic circuit is soldered to the jacket of relay.

Thus, contact system hermetically is insulated from the winding of relay and surrounding air with aid of metal and glass. For the protection of winding of the action of humidity, the lower open part of magnetic system with outputs of winding fills with epoxy resin.

The power, necessary for the function of relay, is within the limits from 0.22 to 0.32 W. The contacts of relay are intended for the commutation of resistive load 0.5 A with voltage 30 V of direct current. The service life of contacts is more than 10^6 functions.

Overall dimensions of the relay: diameter 7.5 mm, length 12.7 mm (without lead wires). Weight is equal to 3 g (without conclusions 2.5 g).

1-23. Fundamental parameters of relay.

To the fundamental parameters of intermediate (governing) electromagnetic relays, they are related:

a). Commutation possibilities (great quantity of contacts of relay - the pairs of contact springs).

b). Power of function (power, necessary for the complete function of relay).

c). Driving power (nominal power, consumed by the winding of relay).

d). Smallest power of function (minimum power, necessary for the complete function of relay, loaded by one closing or stud switch). [1].

FOOTNOTE [1]. the smallest power of the function of relay is sometimes called critical power or the "sensitivity" of relay according tc power. ENDFOOTNOTE.

e). Switched by the contacts of relay (controlled) power (current, voltage and power, the reliably disruptted by contacts relays during the assigned service life).

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f). Control ratio (ratio of the power, switched by contacts, to the power of the functicn cf relay).

g). Resetting ratio (ratio of the current of release/tempering to the spill current of relay).

h). Triggering time (interval of time from the torque/moment of the closing/shorting of governing circuit to the effect of relay on the contrclled circuit).

i). Greatest frequency of work (greatest pulse frequency, the relayed relays without noticeable distortions).

j). Greatest power capacity in winding (the highest efficiency, scattered by the winding of relay at the assigned temperature of overheating and during continuous duty).

k). Wear resistance (service life) (number of cycles, reliably switched by the contacts of relay with the assigned electrical load of contacts).

l). Reliability of the operation of relay, characterized by the probability of its failure-free operation during the specific time (1, 10, 100 h and so forth).

m). Overall dimensions (space) and weight.

To the electromagnetic relay, intended for operation in movable equipment, are imposed the supplementary requirements:

a). Thermal stability and cold stability (property of relay to retain its efficiency at the increased and reduced ambient temperature).

b). Moisture resistance (property of relay to remain operable in medium with the increased relative humidity - is above 80o/o).

c). Vibration resistance (property of relay to retain its efficiency under the influence of vibration) and vibration stability.

d). Stability to the effect of linear (centrifugal) acceleration.

e). Impact stability and impact strength.

f). Height (property of relay to remain operable under operating conditions at the lowered/reduced atmospheric pressure).

g). Airtightness, dust-protection, splash resistance or water-resistance.

h). resistance to tropical conditions.

a). Commutation possibilities of relay.

One Of the fundamental parameters of electromagnetic relay are its commutation possibilities, i.e., great number of circuits which can control simultaneously one relay.

The commutation possibilities of relay are determined by the peak load (by greatest quantity of contact springs), which it can raise relay.

Table 1-2. Parameters of some types of electromagnetic relays.

(1) Параметры реле	(2) Единицы измерений	(3) Тип реле РКН	РПН	РЭС14	РКМП (РКМП-1)	РМУ	РС—52 (РСЧ-52)	РЭС22	РЭС6
(4) Количество контактных групп	шт (5)	2	3	4	2	2	2	2	2
(6) Наибольшее количество контактных пружин	шт	18	18	24	18	12	18	12	6
(7) Ампер-витки срабатывания при 1 переключающем контакте	(8) ав	75	84	110	80	100	136 (117)	62	150
(9) Мощность срабатывания при 1 переключающем контакте	(10) мвт	21,1	31,6	54	33,6	107	172 (128)	65	322
(11) Мощность срабатывания при номинальной нагрузке	(12) вт	0,12—0,34	0,16—0,56	0,19—0,47	0,49—0,58	0,62—0,72	1,3—1,5	0,26	0,5—0,8
(13) Время срабатывания нормальных реле	(14) мсек	7—80 (5—80)	7—70	10—60	6—50	4—40	3—25	2—9	2—10
(15) Время срабатывания замедленных реле	»	10—120	20—80	15—100	10—60	—	—	—	—
(16) Время отпускания нормальных реле	»	8—100 (5—60)	6—50	5—30	6—50	1,5—6	3—8	0,8—2,5	1,5—3,0
» » (17) замедленных реле	» (14)	30—600	20—300	30—250	20—200	18—80	12—50	—	5—10
(18) Усредненное сопротивление 1 витка (при $k_з = 0,6$)	10^{-6} ом	3,75	4,5	4,47	5,24	10,7	9,3	12,8	14,0
(20) Приведенная индуктивность 1 витка при непритянутом якоре (макс.)	10^{-8} гн (21)	24	23	15	22	14,5	7,7	8,7	8,6
(22) Приведенная индуктивность 1 витка при притянутом якоре (макс.) $\delta_0 = 0,1$ мм	10^{-8} гн (21)	38	38	25	33	31	12,4	16,0	13,7
(23) Приведенная индуктивность 1 витка при частоте 1000 гц	10^{-8} гн (21)	1,45	1,6	1,3	1,9	1,95	1,98	2,2	1,5
(24) Наибольшая мощность в обмотке (при $\vartheta = 60°$ C)	(12) вт	6	5	4,3	4,3 (3,5)	2,5 (2,2)	3,0 (2,4)	1,25	1,4
(25) Размеры магнитопровода:									
(26) диаметр сердечника	мм	9	4 × 10,5	7,5	9	8	8	2,5 × 5	5
(27) сечение сердечника	(29) $см^2$	0,636	0,42	0,44	0,636	0,50	0,50	0,125	0,19
(28) сечение полюса	»	1,77	1,60	1,63	1,54	0,50	0,50	0,20	0,50
(30) длина сердечника	мм	70	74	60,5	54,5	32	40	21,7	22
(31) Средняя длина магнитопровода	(29) см	17,6	17,2	15,2	13,9	9,0	10,8	5,8	6,2
(32) Регулировочные параметры:									
(33) ход якоря	мм	0,8	1,1—1,5	1,5	0,9±0,1	0,4±0,1	1,1±0,1	0,3	0,6
(34) высота штифта	»	0,1—0,5	0,1—0,5	0,1—0,2	0,05—0,3	—	0,05—0,1	0	0,1
(35) Давление в замыкающих контактах	Г (36)	17—22	18—25	18—22	20—25	> 35	18—26	10—16	> 12
(36) Давление в размыкающих контактах	Г	17—22	18—25	18—22	20—25	20—25	18—26	> 10	> 12
зазор между контактами	мм	0,3—0,8	0,4—0,6	0,4—0,5	0,3—0,8	> 0,4	> 0,35	> 0,3	> 0,35
(37) Размеры обмоточного пространства:									
(38) внутренний диаметр обмотки	мм	9,5	4,3 × 10,8	8,8	9,8	8,8	8,8	4,9	5,5
(39) высота щеки катушки	»	7,6	7,2	6,5	6,7	4,6	4,1	3,75	3,5
(40) высота обмотки	»	6,7	6,6	5,5	6,0	3,9	3,5	3,35	3,0
(41) длина обмотки	»	59,1	50	54,5	46	28	34,5	17,6	18,5
(42) сечение окна обмотки	$мм^2$	396	330	300	276	109	121	59,0	55,5
(43) Габаритные размеры реле:									
(44) ширина	мм	26,5	26	22	25 (31,6)	23,7	17 (24,7)	19,5	19
(45) высота	»	56,5	38	47 (39)	56 (50,4)	41,0	50 (58,5)	29,5	26,5
(46) длина	»	95	108	80 (66)	80 (89)	39,5	61 (70)	36,5	38,9
(47) площадь фасада	(29) $см^2$	15,0	9,9	10,3	14,0 (15,9)	8,65	8,5 (14,5)	5,76	5,03
(48) объем	(29) $см^3$	142	107	83	112 (124)	34,1	52,0 (101,0)	21,0	19,5
(49) Удельные размеры реле:									
(47) площадь фасада	(29) $см^{2*}$	1,7	1,1	0,86	1,56 (1,77)	1,44	0,94 (1,61)	0,96	1,67
(48) объем	(29) $см^{3*}$	15,8	11,9	6,9	12,5 (15,8)	5,7	5,8 (11,2)	3,5	6,5
(50) Вес реле при наибольшей нагрузке	г (51)	290	240	170	190 (270)	75	90 (110)	36	32
(52) Удельный вес реле	г*	32,2	26,7	14,2	21,1 (30)	12,5	10 (12,2)	6	10,7
(53) Вес активных материалов:									
(54) сталь	г	106	79	55	78	28	40	8,0	9,8
(55) медь	»	110	80	75	65	22	25	5,8	6,5
(56) Вес якоря реле	»	11,9	34	6,4	14,7	5,8	7,3	1,5	1,3
(57) Наибольшее напряжение на обмотке	в (58)	100	100	100	250	250	250	220	100
(59) Номинальный ток в цепи контактов	а (60)	2; 0,2	0,2	0,1 (1)	2; 0,2; 0,1	1; 0,10	2; 0,125	3; 2; 0,3	6; 2; 0,1
(61) Номинальное напряжение на контактах	в (58)	36; 60	60	60	32; 60; 300	27; 300	25; 300	30; 30; 220	28; 30; 300
(62) Испытательное напряжение обмотки и контактов	в (58)	500	500	500	1100	1000	1100	500	500
(63) Срок службы реле при номинальной активной нагрузке	(64) циклов	10^6; 10^7	10^7	$3 \cdot 10^7$ (10^7)	10^6; 10^7; 10^8	10^8	10^8	10^4; 10^6; 10^8	$5 \cdot 10^6$; $1,5 \cdot 10^6$; $2 \cdot 10^6$.

Key: (1). Parameters of relay. (2). Units of measurements. (3). Type of relay. (4). Quantity of contact groups. (5). pcs. (6). Great quantity of contact springs. (7). Ampere-turns of function with 1 stud switch. (8). AV. (9). Power of function with 1 stud switch. (10). mW. (11). Power of function with nominal load. (12). W. (13). Triggering time of normal relays. (14). ms. (15). Triggering time of time-lags relay. (16). Releasing time of normal relays. (17). time-lags relay. (18). the averaged resistor/resistance of turn (with k_3 = 0.6). (19). ohm. (20). Given inductance of 1 turn with the nonpullled armature (max.). (21). H. (22). Given inductance of 1 turn with the pulled armature (max.) δ_1 = 0.1 mm. (23). Given inductance of 1 turn with frequency of 1000 Hz. (24). Highest efficiency in winding (at ϑ = 60°C). (25). Size/dimensions of magnetic circuit. (26). the diameter of core. (27). the section of core. (28). the section of pole. (29). cm. (30). the length of core. (31). Average length of magnetic circuit. (32). Regulating parameters. (33). the course of armature. (34). the height/altitude of plug. (35). Pressure in circuit closing contacts. (36). Pressure in the breaking contact the gap between contacts. (37). Size/dimensions of winding space. (38). the inner diameter of winding. (39). the height/altitude of the jaw

of coil. (40). the height/altitude of winding. (41). the length of winding. (42). the section of the window of winding. (43). Overall dimensions of relay. (44). width. (45). height/altitude. (46). length. (47). the area of facade. (48). space. (49). Specific size/dimensions of relay. (50). Weight of relay with full load. (51). g. (52). the specific gravity/weight of relay. (53). Weight of active materials. (54). steel. (55). copper. (56). Weight of the armature of relay. (57). Maximum voltage on winding. (58). V. (59). Nominal circuital current of contacts. (60). A. (61). Nominal voltage on contacts. (62). the testing voltage of winding and contacts. (63). Service life of relay with nominal resistive load. (64). cycles.

FOOTNOTE *. To one pair of contact springs. ENDFOOTNOTE.

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The full load of relay depends on the size/dimensions of relay, and also on form and relative value of the pole

piece, which determine the character of the electromechanical characteristic of relay.

Table 1-2 gives given data on commutation possibilities and the size/dimensions of magnetic circuit for the different types of electromagnetic relays.

For a comparison in Fig. 1-24 and 1-25 are given the load and electromechanical characteristics of different relays. Full-load saturation curves were remove/taken with nominal for each type relay clearance; they were constructed in function of the required power. Electromechanical characteristics are given for power 0.2 W.

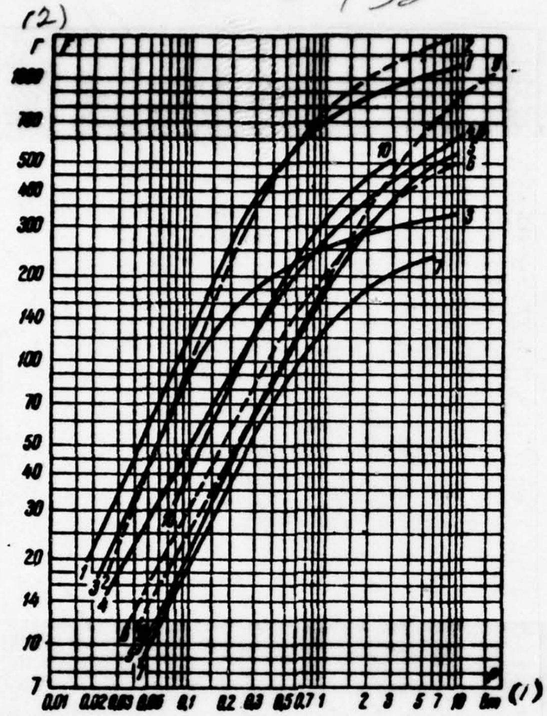

Fig. 1-24. Full-load saturation curves of different types of relay (with nominal clearances). 1 - type RKN (σ = 1.1 mm); 2 - type RKN without the pole piece (σ = 1 mm); 3 - type RPN (σ = 1.5 mm); 4 - type RKM-1 (σ = 1.1 mm); 5 - type RS-13 (σ = 1.0 mm); 6 - type RS-13 with the pole piece (σ = 1.0 mm); 7 - type RSM (σ = 0.6 mm); 8 - type RS-52 (σ = 1 mm); 9 - type MKU-48 (σ = 1 mm); 10. type RMU (σ = 0.4 mm).

Key: (1). W; (2) g.

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From full-load saturation curves it follows that the greatest attracting force with loads above 120 g has relay of the type RKN, after it with loads to 200 g, go by the relay of types RPN, RMU, RKM-1 and RS-52.

With loads it is more than 200 g the characteristics of relay RMU, RKM-1 and RS-52 intersect the curves of a relay of the type RPN.

The curves of the dependences of attracting force on the required power and electromechanical characteristics during the comparison between themselves of the different types of relay give incomplete picture, since the constructions of contact springs and groups for the different types of relay are different, and consequently, value and type of load on armature, created by uniform contact groups, for the different types of relay are different. Therefore for the comparison between themselves of the different types of relay Fig. 1-26 gives the curves of the dependences of conditional work on the course of armature at power 0.2 W and with nominal sizes of plugs.

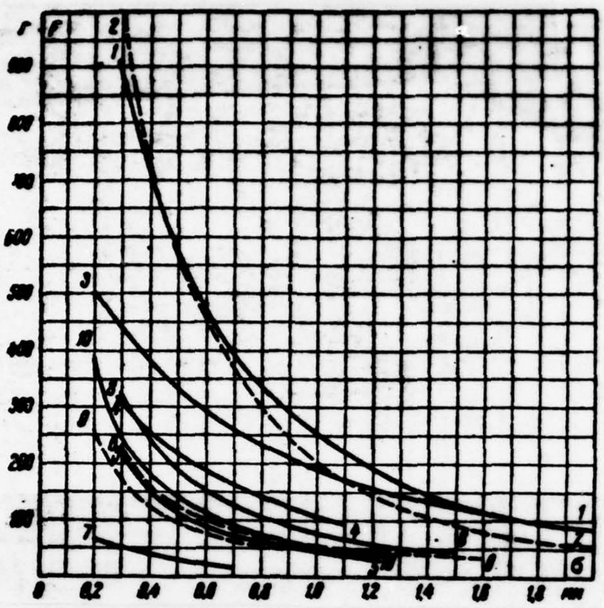

Fig. 1-25. electromechanical characteristics of different types of relay (with P = 0.2 W). 1 - type RKN; 2 - type RKN without the pole piece; 3 - type RPN; 4 - type RKM-1; 5 - type RS-13; 6 - type RS-13 with the pole piece; 7 - type RSM; 8 - type RS-52; 9 - type MKU-48; 10 - type RMU.

[Γ = g]

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During the comparison of the different types of relay us interests in the final analysis not the attracting force, created by the armature of relay at different power, but the power (or ampere-turns), necessary for the closing/shorting (or interrupting) of one or the other number of contacts. Consequently, for the comparison among themselves of the different types of electromagnetic relays to conveniently have curves of dependences of the required power on the load of relay that which was measured not in grams, but expressed as a quantity of pairs of contact springs. However, depending on the circuit of contact group, this power with just one number of springs can be different. Thus, for instance, closing and breaking contact with the identical number of contact springs require different power; two changing over three circuit closing contacts with the identical number of springs also require different power. Therefore for obtaining the comparable results, is most better applied uniform loading, i.e., to load the compared relays with identical contacts.

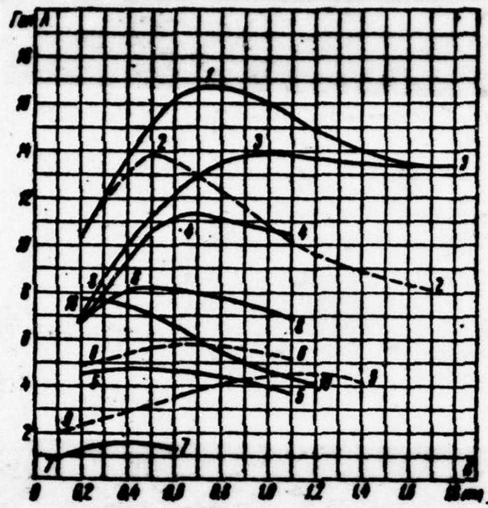

Fig. 1-26. Curved of conditional work of different types of relay (with P = 0.2 W). 1 - type RKN (δ_0 = 0.3 mm); 2 - type RKN without the pole piece (δ_0 = 0.2 mm); 3 - type RPN (δ_0 = 0.3 mm); 4 - type RKM-1 (δ_0 = 0.2 mm); 5 - type RS-13 (δ_0 = 0.2 mm); 6 - type RS-13 with the pole piece; 7 - type RSM (δ_0 = 0.1 mm); 8 - type RS-52 (δ_0 = 0.1 mm); 9 - type MKU-48 (δ_0 = 0.2 mm); 10. type RMU (δ_0 = 0).

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Figures 1-27 gives the curves of the dependences of the required power during function on the number of pairs

of contact springs for the different types of relay. From these curves it follows that the smallest power with uniform loadings it consumes relay of the type RKN, for it go by the relay of types RPN, RKM-1 and RMU.

b) The smallest ampere-turns and the power of function.

Under the smallest (critical) ampere-turns of excitation, necessary for the complete function of the normally controlled relay, loaded by one closing (or changing over) contact.

For the comparison among themselves of the different types of relay, is more right to estimate the quality of their construction not on the smallest ampere turns, but according to the smallest (critical) power, necessary for the complete function of relay, loaded by one closing (or changing over) contact, during normal adjustment of this relay and with filling of entire winding space of coil.

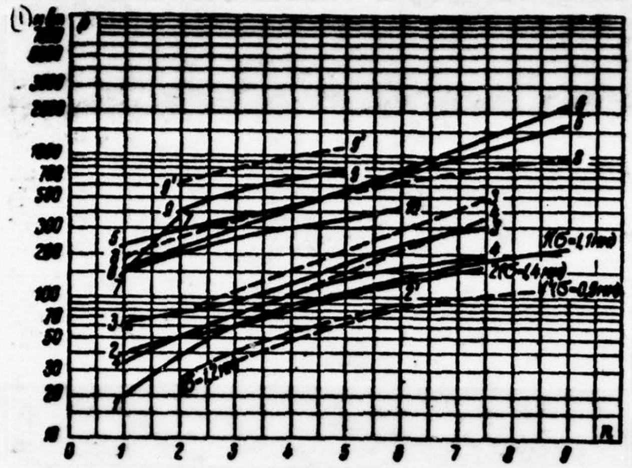

Fig. 1-27. Power curve, consumed by different types of relay (n - number of pairs of contact springs). 1 - type RKN; 2 - type RPN; 3 - type RKM-1; 4 - type RKM-1 without return spring; 5 - type RS-13; 6 - type RS-13 with pole pieces; 7 - type RSM; 8 - type RS-52; 9 - type MKU-48; 10 - type RMU.

Key: (1). mW.

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Since the power, consumed by relay, depends not only on ampere-turns, but also from size/dimensions and the construction of coil, relay of different type with the

identical ampere-turns of function they can consume different power.

Other conditions being equal, the power, consumed by relay, depends also on the temperature of winding, diameter of wire and thickness of its insulation. Therefore for obtaining the comparable results during the computation of the power, consumed by relay, let us accept the temperature of the winding of equal to +20°C and duty factor k_3 = 0.6 (this corresponds to the wire of the brand PEL by diameter 0.14 mm).

The power, required by relay during function, is equal to:

$$P_c = I_c^2 r,$$

where I_c - a current of operation (critical current) and

r - winding impedance with θ_0 = +20°C and k_3 = 0.6.

Substituting in this equation for r its value from formula (6-12), we obtain for the critical power of relay the following expression:

$$P_c = I_c^2 C w^2 = C \cdot AW_c^2, \qquad (1\text{-}1)$$

where AW_c - the ampere-turns of function (critical ampere-turns).

Critical ampere-turns characterize by themselves the quality of the construction of magnetic relay circuit, and value C - the form of the section of the core and the size/dimensions of coil.

Table 1-2 gives corrected values of ampere-turns and power of the function of the different types of the relays, loaded by one stud switch. In brackets are given the values AW_c and P_c for relay of the type RS52 with the pole piece. Furthermore, in this table are given the size/dimensions of winding space and value of quantities C (at k_3 = 0.6).

The smallest power of function has a relay of the type RKN, for it go the relay of types RPN, RKMP, RES14 and RES22.

c) Triggering time and release/tempering.

The time delay depends on section and length of core,

conductivity of clearance, safety factor on ampere-turns and the safety factor according to power.

With an increase in section and lengths of core, other conditions being equal, the time delay increases.

Figures 1-28 gives the curves of the dependences of triggering time of the different types of relay on the value of coefficient m (reserve according to power) and power input with dual reserve on ampere-turns and load by one changing over (reversing) contact. (Relay of the type RES9 has two stud switches).

Dotted line designated the curves of triggering time of the breaking contact.

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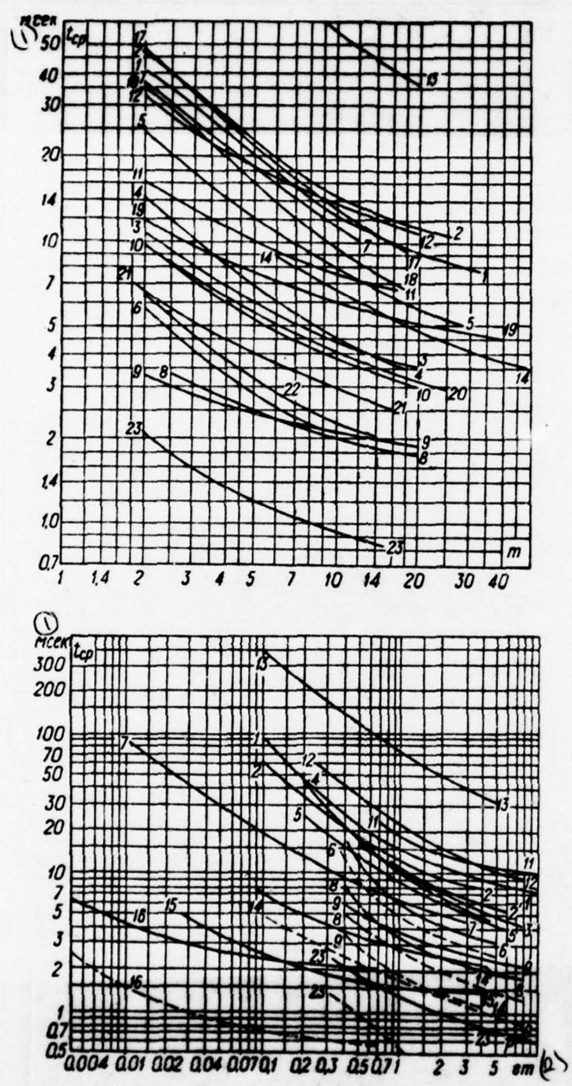

Fig. 1-28. Characteristics of triggering time of different types of relay with coefficient of reserve K_1 = 2 (load is one stud switch). 1 - type RPN; 2 - type RKN; 2' - type RKN without the pole piece; 3 - type RS-13; 4 -

type RMU; 5 - type RKM-1; 6 - type RES6; 7 - type RDCG; 8 - type RES9; 9 - type RES10; 10 - type RS-52; 11 - type MKU-48; 12 - type KDR-1; 13 - increased mock-up of relay of the type RKN x 2; 14 - type TRM; 15 - type RP-7; 16 - type RP-4; 17 - type RES14; 18 - type RKMP; 19 - type RES8; 20 - type TKYe52; 21 - type TKYe21; 22 - type RES22; 23 - type RES15.

Key: (1). ms. (2). et.

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For a comparison in Fig. 1-28 are plotted tentative curves to triggering time of the mock-up of relay with circular core of diameter 18/30 mm (increased two times of relay of the type RKN). From figure it follows that with the size decrease of relay (section of ccre) triggering time of electromagnetic relays decreases.

With m = 5, time delay of types RKN, RPN, KDR1 and RKMP is within the limits from 16 to 23 ms of, those of types RKM-1 and MKU-48 - from 10 to 12 ms, types RMU, RS-13 and RS-52 - from 5.2 to 6.8 ms and types RES6,

RES9 and RES10 - from 2.4 to 2.8 ms. With power in 1.5 W triggering time of the mock-up of relay (RKN x 2) is equal to 60 ms, relay of type KDR-1 - 17 ms, the type MKU-48 - 15 ms, the type RPN - 13 ms, the type RKN - 10 ms, relay of type RKM-1 - 6.5 ms, type RES6 - 4.5 ms and the type RES10 - 3 ms.

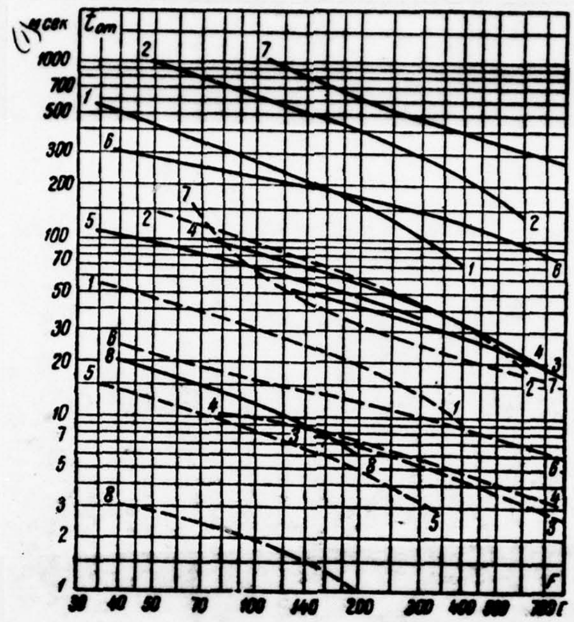

Fig. 1-29. Characteristics of releasing time of various types of relay. Solid lines - with the shorting of winding; broken - with the disconnection of winding. 1 - type RPN (δ_0 = 0.1 mm); 2 - type RKN (δ_0 = 0.1 mm); 3 - type RS-13 (δ_0 = 0.1 mm); 4 - type RMU (δ_0 = 0); 5 - type RKM-1 (δ_0 = 0.1 mm); 6 - type KDR-1 (δ_0 = 0.2 mm); 7 - type KDR3 (δ_0 = 0.06 mm); 8 - type RES6 (δ_0 = 0.1 mm).

Key: (1). ms.

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At small power (to 0.5 W) triggering time of polar relays is considerably shorter than triggering time of electrcmagnetic (neutral) relays.

Figures 1-29 gives dependence curves cf the releasing time of the different types of the normal and deferred-action (by means of the shorting of their winding) relays. The curves of the releasing time of normal relays are constructed by dotted line. From figure it follows that with an increase in the size/dimensions cf relay (section of core) the releasing time increases.

With load in 200 g, the releasing time of the mock-up of time-lag relay (RKN x 2) is equal to 9 s, time-lags relay of type KDR-3 - 0.6 s, the type RKN - 0.42 s, the type RPN - 0.16 s and type RKM-1 - 0.046 s.

d) Overall dimensions and weight.

The load of relay (number of contact springs) can

change within sufficiently wide limits; therefore for the comparison between themselves of the different types of relay, it is necessary, besides overall overall dimensions and the weight of these relays, to introduce the appropriate specific values: 1) the specific gravity/weight of relay, i.e., the weight, which is necessary to one pair of contact springs, and 2) the specific overall size of relay, i.e., the space, which is necessary to one pair of contact springs.

Under overall size it is usually accepted to understand space (in cm^3), occupied by this instrument, but the overall sizes of relay interest us also from the viewpoint of the place, occupied by them on board (stand). Therefore, besides specific volume, it is necessary to introduce also the concept of the specific area, occupied by relay on facade (width of relay, multiplied by its height/altitude), i.e., the sectional area of relay, which is necessary to one pair of contact springs.

It is necessary to note that actually the area of board, which is necessary to one pair of contact springs, is somewhat more the specific sectional area of relay, since it depends on the distance between two adjacent

relays (since close to each other cannot be assembled relay). This distance depends on scattering of magnetic circuit, construction of relay and board. The value of this distance varies within limits from 1 to 5 mm. For a reduction in area of the board, which is necessary to one pair of contact springs other conditions being equal to favorably apply relay with a large quantity of contact springs.

Besides gross weight of relay, it is very important to know separately the weight of copper of winding and steel of magnetic circuit.

Table 1-2 gives total and specific gravity/weights, and also the overall dimensions of the different types of electromagnetic relays (without jackets). In brackets are given the corresponding values for these relay in jackets.

The smallest specific size/dimensions and weight it has relay of the type RES22, for it they go by the relay of types RES6, RS-52, RMU, RES14 and RKME.

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1-24. Reliability of the operation of relay.

Electromagnetic relays, just as all other cell/elements of radio-electronic equipment, cannot ensure absolute (100o/o) the reliability of operation.

The fundamental reasons for failure of relay are: the nonpassage of the current through the locked contacts due to filming or contamination of working contact surface, welding (cohesion/coupling) of contacts, change in the regulating parameters, the breaks of winding, the breakdowns of insulation of winding to housing, the breakdowns of the part of the winding with the formation/education of closed loops, the incidence/impingement of filings or dust and the disturbance/breakdown of airtightness (of sealed relay).

The analysis of the reliability of the operation of relay, carried out by firms "Vitro" and "Bell", shows that approximately 15-20o/o of damages of relay falls on the breaks of windings and about 50o/o to the absence of contact as a result of the disturbance/breakdown of

adjustment, contamination of contacts or burning of contact springs [1-12].

Electromagnetic relays usually are related to the cell/elements of radio-electronic equipment for the increased complexity, since they are the device, which consists in essence of three different systems: electromagnetic, movable and contact. Each of these three systems has their special laws of defectiveness.

Efficiency of movable system depends on external mechanical effects, while efficiency of contact system depends complexly on its construction, the parameters of the switched circuits, climatic conditions, mechanical effects, atmospheric pressure and composition of gaseous medium.

The reliability of relay can oscillate within very large limits. Under the reliability of relay, is understood its ability smoothly to function (operate) under the assigned conditions during the established/installed period of time. Is quantitatively reliability rate/estimated at the probability of the failure-free operation or with the intensity (danger) of failures.

Under the probability of failure-free operation, it is accepted to understand the probability of the absence of any failures during the use of relay under the assigned operating conditions during the established/installed period of time.

Most completely reliability is characterized by the probability of failure-free operation, but by failure rate conveniently to use during the calculation of the reliability of the complex equipment, which consists of a large quantity of different cell/elements (if λ = const).

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By failure rate, is understood the relation of a quantity of cell/elements, which refused during the period of time in question, to the product of a quantity of instruments, which smoothly worked at the beginning of this period of time, not its duration.

Figures 1-30 gives the typical curve of a change in the rate of failures of equipment and cell/elements in time. In initial operating cycle for time from 0 to t_1, the failure rate sharply decreases because of breakdown of

the cell/elements of equipment or parts of the relays, which have different defects. This section of curve is usually called period breakings in.

On the section of curve from t_1 to t_2, the failure rate changes very barely and virtually it it is possible to consider constant. This section characterizes the normal operation of equipment and cell/elements (relay).

The last/latter section of curve (is more than t_2) is characterized by an increase in the failure rate because of the mechanical, thermal and electrical wear of the cell/elements of equipment and parts of the cell/elements. This section of curve is called the period of ageing.

The failure of relay is considered the complete or partial loss by it of efficiency, including outputs of its fundamental parameters beyond the established/installed limits. Failures can be divided into complete and partial.

Complete failure is characterized by the total loss of efficiency and usually it begins suddenly as a result of an abrupt change in values one or of several fundamental parameters of cell/element (relay).

To the complete failures of relay, they are related:

a) the damage of winding (breaks, the short circuit of the part of the winding, by the sample/test of insulation for housing);

b) the damage of movable system (jamming/seizing or the wedging of armature, a breakdown in the springs or pushers (backstops);

c) spontaneous interruptings or closing of contacts ("auto/self-function") under the mechanical influences;

d) the loss of the commutation ability (nonclosing/shorting or noninterrupting) of contacts or the breakdown of insulation of contacts.

The nonclosing/shorting of contacts occurs as a result of the formation/education of the badly/poorly conducting films or coatings, incidence/impingement into the contact points of the extraneous insulating particles or loss of contact pressure due to large erosion of contacts or deformation of springs.

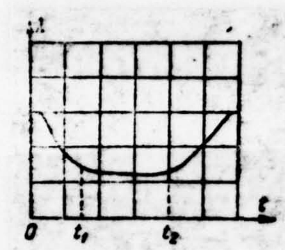

Fig. 1-30. Bathtub curve.

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Noninterrupting contacts is obtained as a result of the random welding (cohesion/coupling) of contacts, wedging of the outgrowths (needles) of one contact in the crater opposite, the formation/education of bridge, which overlaps intercontact gap, the nonextinctions of the arc between contacts or the breakdown of the insulation between contact springs.

Partial failure in the majority of cases is conditional and is characterized by deterioration in the parameters, calling the loss of the ability of the execution of functions only within the assigned limits. The obviousness

of failure in this case depends on the character of the use of relay in the equipment: under some conditions it is led to the failure of equipment, in others - does not cause even deterioration in its work.

To partial failures it is related:

a) an increase in the current (voltage) of function higher than established/installed norm or reduction in current (voltage) of release/tempering lower than established/installed norm;

b) an increase in the contact resistance higher than assigned norm;

c) a decrease in the insulation resistance lower than established/installed norm;

d) output beyond the established/installed limits of other parameters (for example time characteristics and so forth), characteristic for this type relays.

Depending on the character of the onset failures can be divided into three groups, which determine three sections

of the distribution curve of failure rate in time.

1. Failures due to manufacturing defects. Examples of the failures of this group are failures due to the disturbance/breakdown of the poor quality solderings of conclusions, poor weldings of parts (in particular contacts), the weakening of threaded connections, failures in contacts because of low contact pressure, contamination and the poor processing of the contact surface, etc. For a decrease in the quantity of such failures, can be recommended the introduction of the training/aging of all relays under the critical conditions, which lead to the identification of potentially possible failures - the "burning-out" of articles with potential defects. The duration of this training/aging is determined by period breakings in and it must compose the small part of the assigned resource/lifetime of relay.

2. Failures, which appear as a result of gradual wear of parts or ageing of materials, which give rise to presence of section of "ageing" in distribution curve of failure rate in time. To these failures can be attributed, for example, the failures of contacts due to their wear, the failures of winding during prolonged heating because of the ageing of insulation, reduction in current of

release/tempering lower than assigned norm, an incidence/drop in the insulation resistance or by its sample/test as a result of the deposit of the products of atomization/pulverization and erosion of contacts on the base of relay, etc.

The period of ageing must lie/rest beyond the limits of the established/installed service life of this type relay.

3. Failures, which appear are earlier than period of ageing and appearing as a result of manifestation of effect of different factors or concealed/latent defects, which have random nature.

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An example of such failures it is possible to consider failures because of the concealed/latent damages of the wire of winding, the short duration failures of contacts due to the incidence/impingement of dust or wear products of movable parts, etc.

The failures of this group give rise to the presence

of the section of "normal operation" the distribution curve of failure rate in time.

Failure rate according to the given determination can be expressed by the following formula:

$$\lambda(t)=\frac{m_i}{\Delta t_i}\cdot\frac{1}{M_0-m(t)}, \qquad (1\text{-}2)$$

where m_i the number of objects (relay or contacts), which refused for time Δt_i; Δt_i - the duration of the i interval of observation; M_0 - the space of selection (number of tested objects) and of m(t) - the number of objects, which refused up to the moment of time t_i, moreover value $m(t)=\sum_i^t m_i$.

Let us rewrite expression (1-2) in the form

$$\lambda(t)=\frac{\frac{m_i}{M_0\Delta t_i}}{1-\frac{m(t)}{M_0}}. \qquad (1\text{-}2a)$$

In last/latter equation the numerator can be replaced by the differential function f(t), and term $m(t)/M_0$ denominator - by the integral function F(t) the distribution of failures in time.

In this case

$$\lambda(t)=\frac{f(t)}{1-F(t)}=\frac{F'(t)}{1-F(t)}. \qquad (1\text{-}3)$$

Is expressed failure probability F(t) through the probability of failure-free operation (reliability) P (t); then

$$\lambda(t)=\frac{[1-P(t)]'}{P(t)}=-\frac{P'(t)}{P(t)} \qquad (1\text{-}4)$$

or

$$\lambda(t)\,dt=-\frac{dP(t)}{P(t)}. \qquad (1\text{-}4a)$$

Integrating this equation within the limits of preset time t, we obtain:

$$\int_0^t \lambda(t)\,dt=\ln P(0)-\ln P(t)$$

or

$$P(t)=P(0)\,e^{-\int_0^t \lambda(t)\,dt}. \qquad (1\text{-}5)$$

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In the particular case when failure rate constant value λ = const and P(0) = 1, the probability of failure-free operation will be expressed by the following formula:

$$P(t)=e^{-\lambda t}, \qquad (1\text{-}6)$$

if

$$\lambda t<0{,}05, \text{ then } P(t)\approx 1-\lambda_t t.$$

From formula (1-6) we find for a failure rate:

$$\lambda_t=-\frac{\ln P(t)}{t}=-2{,}3\,\frac{\lg P(t)}{t}. \qquad (1\text{-}7)$$

The rate of failures of the contacts of relay is more convenient to express by the number of failures not per time unit, but for one commutation (function).

In this case with a constant value of failure rate, the probability of failure-free operation will be equal to:

$$P(N) = e^{-\lambda N} \approx 1 - \lambda_N N \qquad (1\text{-}6a)$$

and rate of failures

$$\lambda_N = -\frac{\ln P(N)}{N} = -2{,}3\frac{\lg P(N)}{N}, \qquad (1\text{-}7a)$$

where N is a number of commutations (functions) of relay.

The dependence between values λ(t) and λ(N) obviously it is possible to express by the formula:

$$\lambda(t) = \lambda(N)\frac{N_{max}}{t_{max}}, \qquad (1\text{-}8)$$

where N_{max} is the assigned number of commutations of relay in equipment (service life of contacts) and t_{max} - the operating time of equipment, during which the relay must fulfill (master) the assigned number of commutations.

If, for example, rate of failures of contacts is constant and equal to $1 \cdot 10^{-7}$ failures for 1 commutation, then with service life, equal to 10^5 commutations, the probability of the failure-free operation of relay, according

tc formula (1-6a), will be equal to:

$$P \approx 1-\lambda N = 1-1\cdot 10^{-7}\cdot 10^{5} = 1-0{,}01 = 0{,}99.$$

If for relay is required to guarantee smaller service life - only to 10^4 commutations, then its reliability will increase to P = 0.999.

The rate of failures of relay per time unit, if its service life in time is equal to 1000 h and for this time of relay must master 10^5 commutations, according to formula (1-8), must be equal to

$$\lambda_t = 1\cdot 10^{-7}\frac{10^5}{1000} = 1\cdot 10^{-5} \text{ failures on 1 h.}$$

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The failure probability of the relay, which has two (or it is more) contact groups, will be respectively more than in relay with one contact group, but it is not proportional to a quantity of groups. Therefore for the more precision determination of the value of the rate of failures of the contacts of the relays, which have a different quantity of contact groups, it is desirable to determine failure rate separately for each type (certificate) of relay.

If value λ is not constant and defect level is small, then for evaluating the reliability of relay one should use the averaged failure rate:

$$\lambda_t = \frac{m}{\sum_{i=1}^{M_0} t_i} \quad \text{and} \quad \lambda_N = \frac{m}{\sum_{i=1}^{M_0} N_i}. \qquad (1\text{-}76)$$

Upper boundary of the averaged rate of failures (taking into account confidence interval) can be expressed by following formulas [1-32]:

$$\hat{\lambda}_t = \gamma\lambda_t = \frac{b_c}{\sum_{i=1}^{M_0} t_i} \quad \text{and} \quad \hat{\lambda}_N = \gamma\lambda_N = \frac{b_c}{\sum_{i=1}^{M_0} N_i}, \qquad (1\text{-}9)$$

where γ is a coefficient for the calculation of confidence limit; b_c is the coefficient whose value depending on the taken confidence coefficient α and the number of failures m is given in Table 1-3; $\sum_{i=1}^{M_0} t_i = t_1 + t_2 + \ldots + t_k + (M_0 - k)\, t_{max}$ is total time of the work of an entire selection to the final adjustment of preset time (operating time).

In the absence of failures (m = 0) and of the confidence coefficient, equal to α = 0.9, value $b_c = 2.3$.

Table 1-3. Values of coefficient b_c

m \ α	0,90	0,95	0,99	m \ α	0,90	0,95	0,99
0	2,30	2,99	4,61	11	16,6	18,2	21,5
1	3,89	4,74	6,65	12	17,4	19,4	22,8
2	5,32	6,30	8,40	13	18,8	20,7	24,2
3	6,69	7,75	10,1	14	19,9	21,9	25,5
4	7,98	9,15	11,6	15	21,1	23,1	26,8
5	9,28	10,5	13,1	16	22,3	24,0	28,1
6	10,5	11,8	14,6	17	23,4	25,2	29,3
7	11,7	13,2	16,0	18	24,6	26,4	30,6
8	13,0	14,4	17,4	19	25,8	27,6	31,9
9	14,2	15,7	18,8	20	26,9	28,8	33,1
10	15,4	17,0	20,2				

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In this case upper boundary of the averaged failure rate will be equal to:

$$\hat{\lambda}_N = \frac{2,3}{M_0 N}. \qquad (1\text{-}9a)$$

At one failure (m = 1) and α = 0.9 value $b_c = 3,89$, and the averaged failure rate will be expressed by the following formula:

$$\hat{\lambda}_N = \frac{3,89}{N_1 + (M_0 - 1) N_{зап}}, \qquad (1\text{-}9б)$$

where N_1 is a number of commutations of the refused contact and $N_{зап}$ - the assigned number of commutations of relay.

The theoretical calculation of the reliability of relay due to complexity and diversity of the laws of their

defectiveness is very difficult; therefore the quantitative estimate/evaluation of the reliability of relay is usually the result of spot checks of finished articles in the varied conditions of their application/use.

For this purpose from a total quantity of presented relays (the general population) it is take/selected certain quantity of specimen/samples and is carried out their qualification test.

Usually the general population is considered the production, prepared during the period between next tests. From it after definite intervals of time (for example in a month or the block) by uniform party/batches is accumulated the selection; in this case must be provided equal probability for all relay hit this selection.

The minimum quantity of specimen/samples, which it is necessary to select for tests (space of selection) it depends on confidence coefficient, the predicted lower boundary of the reliability of relay and permissible number of failures.

The space of selection with confidence coefficient 0.9

can be determined with the aid of curves, given in Fig. by 1-31 [1-33]. These curves can be used for the solution of the reverse problem - determination of lower boundary of the reliability of relay with $\alpha = 0.9$. The space of the selection of relay must be not more than 10o/o of the general population.

In the particular case in the absence of failures and confidence coefficient 0.9, space of selection M_0 can be determined with the aid of the formula (1-9a) from which we find:

$$M_0 = \frac{2,3}{\lambda N}. \quad (1\text{-}10)$$

Substituting in last/latter equation for λ its value from formula (1-7a), we will obtain for the value of the minimum space of selection, in the case of the absence of **failures with $\alpha = 0.9$, the following expression.**

$$M_0 = -\frac{1}{\lg P}. \quad (1\text{-}11)$$

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With the aid of this formula we find, for example for the probability of failure-free work $P = 0.9$ at $m = 0$, value $M_0 = 21.7 \approx 22$, and for $P = 0.99$-$M_0 = 230$.

Specimen/sample tests of relay for reliability are

carried out to conformity to all point/items of technical requirements.

The conditions, the sequence and the duration of tests, and also the controlled/inspected and measured parameters of relay must correspond to the established/installed procedure of the tests of relay for reliability.

After the measurements of the parameters under normal conditions, one should conduct first testing under the cyclic influence of the temperature, then at lowered/reduced and at elevated temperatures; further is carried out contact testing for service life (under normal conditions) and finally for the effect of vibration, of uniform accelerations, impacts and increased humidity.

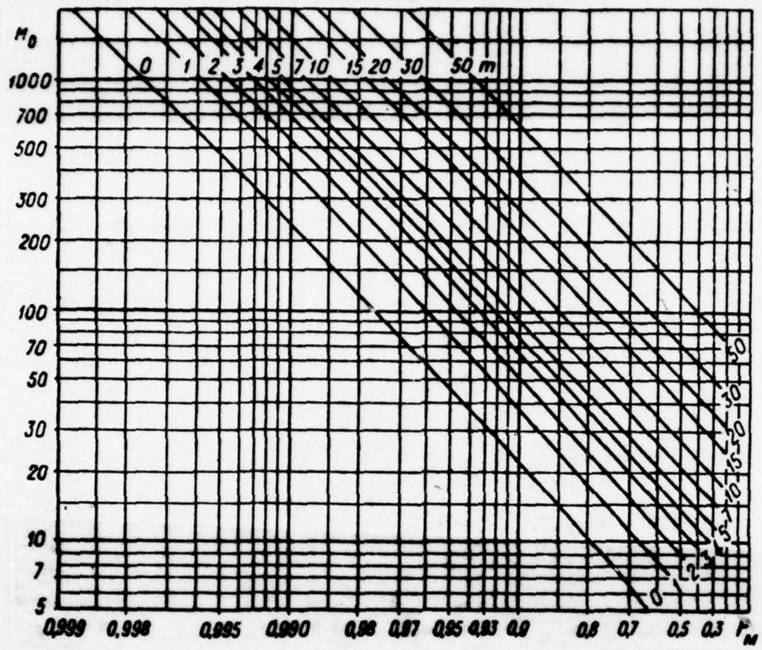

Fig. 1-31. Curved of dependences of minimum space of selection on lower confidence limit of probability of failure-free operation with different number of failures and α = 0.9. [m = t]

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During reliability tests, each first complete or partial failure of any specimen/sample of relay in this conditions/mode testing is record/fixed, and the refused specimen/sample of relay is remove/taken from further tests.

Lower boundary of the probability of failure-free operation can be determined with the aid of curves, given in Fig. 1-31.

In the particular case in the absence of failures (m = 0) and of confidence coefficient 0.9, it is possible to use formula (1-6a), substituting for λ its value from formula (1-9a); we obtain for lower boundary of the probability of the failure-free operation of relay the following expression:

$$P_{\text{н}} = e^{-\lambda N} = e^{-\frac{2,3}{M_0}} \approx 1 - \frac{2,3}{M_0}. \qquad (1\text{-}12)$$

If, for example, during the tests of selection into 22 specimen/samples of relay (M_0 = 22) will not be obtained not one failure, then lower boundary of the reliability of relay will be equal to:

$$P_{\text{н}} = e^{-0,105} = 0,90.$$

For obtaining the more accurate results (decrease in the width of confidence interval) in the case of the absence of failures when conducting of the complete cycle of all tests these tests can be repeated which is equivalent to the duplication of the space of selection, if in this case does not begin the period of ageing.

For example, if after the repeated tests of 22 specimen/samples of relay will be reveal/detected one failure, then lower boundary of the reliability of relay with $m = 1$, $\alpha = 0.9$ and $2M_0 = 44$ will be, according to the curves of Fig. 1-31, it is equal to 0.911 (instead of 0.90 with $m = 0$ and $M_0 = 22$).

If during the repeated tests this same of selection (22 specimen/samples) will be reveal/detected two or more failures, then obviously occurs the period of ageing, and repeated tests are not considered, but the calculation of lower boundary of reliability is conducted, as noted above, for a single selection with zero failures (i.e. in this case value $P_н$ will be equal to 0.90).

According to the statistical data of the number of American firms [1-28, 1-34, 1-35], the rate of failures of relay in radio-electronic equipment oscillates approximately within limits from $1 \cdot 10^{-8}$ to $1 \cdot 10^{-7}$ failures for 1 commutation or from $1 \cdot 10^{-6}$ to $1 \cdot 10^{-5}$ failures on 1 h of work, which corresponds to the level of reliability from 0.999 to 0.99 in the service life of

10^5 commutations for 1000 h of work. For a miniature airtight relay with two stud switches of the type F (space 4.5 cm^3 and weight 15 g) with the nominal load of contacts (2a-28c) and under normal conditions of operation firm "Ts. P. Kler and Ko" gives the rate of failures of contacts 0.084o/o with the service life of 10^4 commutations (λ = 8.4 • 10^{-8} failures for 1 commutation) or reliability 0.999 with confidence coefficient 0.9 and the service life of 10^4 commutations.

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With ambient temperature +125°C and the same load, the failure rate increases to 0.834o/o (λ = 0.834 • 10^{-6} failures by 1 commutation) and the reliability of the contacts of relay of the type F decreases to 0.992 with 10^4 commutations or to 0.92 with 10^5 commutations.

Firm indicates that during tests according to the check program of quality of 235 tested specimen/samples of relay of the type F at temperature minus 65°C it refused two relays, but during vibration tests at the frequency of more than 1000 Hz and upon accelerations more than 15 g refused six relay [1-36].

Consequently, lower boundary of the probability of failure-free operation of firm "Ts. P. Kler and of Ko" at the extreme values of operating conditions (to temperature -65°C and with vibrations with frequency 2000 Hz during acceleration 20 g), according to the curves of Fig. 1-31, does not exceed 0.945 with α = 0.9 (without taking into account of the failures of contacts).

The reliability of the operation of equipment or instrument as a whole depends on the reliability of the operation of its cell/elements and connection of these cell/elements.

By series connection of cell/elements it is accepted to call such, with which failure at least of one cell/element are led to the failure of an entire system.

Parallel connection of cell/elements is called such connection during which the failure of an entire system occurs only with the failure of all cell/elements.

The composite joint of cell/elements is called such

connection during which occur the consecutive and parallel connections of cell/elements.

The general reliability of equipment (system), consisting of m of the series-connected cell/elements, which have respectively reliability - $P_1, P_2, P_3, \ldots, P_m$, will be equal to:

$$P = P_1 P_2 P_3 \ldots P_m. \quad (1\text{-}13)$$

If the reliability of all cell/elements is identical and equal to P_a, then is the general reliability of the system

$$P = P_a^m. \quad (1\text{-}14)$$

The probability of the failure-free operation of equipment (unit), that provides 20 cell/elements with identical reliability $P_a = 0{,}99$ each, will be equal to:

$$P = 0{,}99^{20} = 0{,}81.$$

The reliability of the operation of two in parallel connected cell/elements with reliability P_A and P_B, which fulfill one and the same function, will comprise:

$$P_{AB} = 1 - (1 - P_A)(1 - P_B). \quad (1\text{-}15)$$

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The general reliability of the operation of system from m of the in parallel connected cell/elements with identical

reliability $\bar{P_A}$, is equal to:

$$P = 1-(1-P_A)^m. \quad (1\text{-}16)$$

The probability of the failure-free operation of system of two in parallel connected cell/elements with identical reliability $P_A = 0{,}9$ will be equal to:

$$P = 1-(1-0{,}9)^2 = 0{,}99.$$

Therefore for an increase in the reliability of the operation of equipment, usually is applied the redundancy (redundancy) of separate cell/elements in circuit (piece-by-piece redundancy) or entire unit with cell/elements as a whole (common/general/total redundancy).

With piece-by-piece redundancy the reliability is always higher than with common/general/total redundancy.

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Chapter Two

MECHANICAL CHARACTERISTICS OF RELAYS.

2.1. General information.

The load of relay consists in essence of the contact springs which during the function cf relay are closed, they are broken or are changed over, forming the necessary circuits.

A quantity of contact springs on relay can change between very wide limits (from 2 to 18 and more springs).

The value of the mechanical effort/forces, encountered by the armature of relay during its motion, does not remain constant, it changes over wide limits. The curve of the dependence of the mechanical effort/forces, overcome by the armature of relay during its displacement/movement, on

the course of armature $F_M = f(\delta)$ is called the mechanical characteristic of relay.

As illustration Fig. 2-1 gives the mechanical characteristic of relay of type 100, loaded by one contact group for closing/shorting [1-14]. Along the axis of ordinates, is deposit/postponed the load in grams, overcome by armature during its displacement/movement, while along the axis of abscissas - clearance in millimeters.

Cut Oa_1 on the axis of abscissas is the value of clearance, Of_1 - the height/altitude of the plug of loosening, and a_1f_1 - the value of the course of armature.

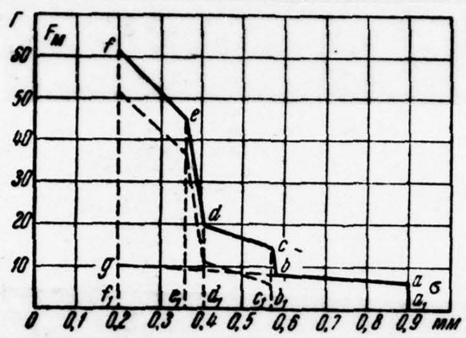

Fig. 2-1. Mechanical characteristic of relay of type 100, loaded by contact group No 1.

[Г = g]

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Section a_1a of mechanical characteristics is a value of the effort/force (measured on the driving/moving plug), which must be applied to the armature of relay in order to overcome initial tension of the return spring of armature. This effort/force, measured at armature, it is usually called the "pressure of armature". The characteristic of the spring of armature is broken line a_1ag.

Normally between the bridge and the driving/moving plug of group is a small distance, called the "freewheeling escapement" of armature; therefore the armature of relay of

the resistor/resistance only of one return spring, which is reflected on the mechanical characteristic of straight line ab. Cut a_1b_1 to value of which in this case is moved the armature of relay, determines by itself the freewheeling escapement of armature.

During further armature travel it presses on the driving/moving plug of group and remove/takes the lower spring of this group from backstop. Section bc of mechanical characteristic reflects by itself the process of relieving the lower spring from backstop. Cut c_1b_1 is the value of armature travel during removal/taking of this spring from backstop. Then lower spring is bent to the contact of its contacts with the contacts of upper spring. The corresponding section of characteristic is direct/straight line cd.

Section de reflects the process of relieving the upper spring from backstop with the aid of the contacts of lower spring and finally the straight line ef reflects the combined curvature (follow of relay springs) of both springs to the end/lead of the course of armature. The follow of relay springs of springs has very large value, since it provides obtaining the assigned pressure in contact. To

avoid a considerable decrease in the contact pressure at the wear of contacts and the displacement ("drift") of upper spring (as a result of the deformation of the separators of contact group in the course of time) the value of the follow of relay springs of springs must be sufficiently greater (not less than 0.2-0.3 mm). Cut b_1f_1 represents the value of the working stroke of the armature of relay.

Thus, the mechanical characteristic of relay is the broken line, which consists of a series of the straight portions, which characterize the separate cell/elements of the work of springs.

For obtaining mechanical characteristics of the contact group No 1, shown by dotted line in Fig. 2-1, it is necessary from the mechanical characteristic of relay to deduct characteristic curve of return spring and to transfer the origin of coordinates into point f_1.

2-2. Calculation of the sagging/deflection of flat/plane contact springs.

For the calculation of the cell/elements of mechanical characteristics, we will use the theory of the bending of the elastic beam, cantilevered and the loaded of end/lead concentrated force F (Fig. 2-2). This method can be used for calculation, since the sagging/deflection of contact springs in comparison with their length is small and does not exceed the limits of elastic deformations.

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Springs with large radius of curvature can be designed as direct/straight springs.

Amount of deflection of beam in any section m, which is located between point B of the application of force F and the place of seal O, is equal to:

$$y = \frac{Fx^2}{6EJ}(3l - x), \qquad (2\text{-}1)$$

where l - length of beam,

x - a distance of section m from bearing edge,

E - modulus of elasticity of material and

J - the second moment of area of beam relative to z axis.

At the point of application of force amount of deflection is equal to:

$$y = \frac{Fl^3}{3EJ} = cF, \qquad (2\text{-}2)$$

where c - flexibility of spring, c = $l^3/3EJ$.

Is expressed distance x through l; then x = kl, where k is the coefficient whose value is equal to the distance ratio x to the length of an entire spring.

Let us substitute into expression (2-1) instead of x its value

$$y = \frac{Fk^2l^2}{6EJ}(3l - kl) = \frac{Fk^2l^3}{6EJ}(3 - k) = cF\frac{k^2(3-k)}{2}. \qquad (2\text{-}1a)$$

If the load of cantilever beam is applied not at end/lead, but in point K, which is located at a distance l_k from bearing edge (Fig. 2-3), then the free end/lead of beam KB to the right of point of application not of load and is not deformed (it remains the straight line).

The complete sagging/deflection of beam in point m,

which is located to the right of the point of application of force is equal to:

$$y=\frac{Fl_k^2}{6EJ}(3x-l_k), \tag{2-3}$$

where $l_k < x$.

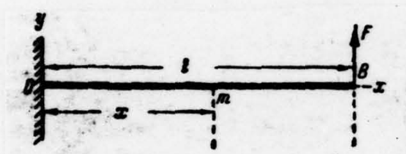

Fig 2-2.

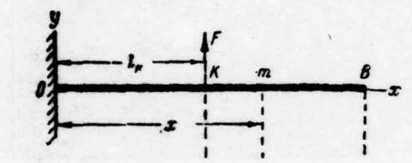

Fig 2-3.

Fig. 2-2. Load is concentrated of end/lead of spring.

Fig. 2-3. Load is applied at a distance l_k from bearing edge of spring.

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If we designate relation x and l_k by k_x, then $x = k_x l_k$. After substituting into equation (2-3) vmesto x its value, we will obtain:

$$y = \frac{Fl_k^3}{6EJ}(3k_x - 1) = c_k F \frac{3k_x - 1}{2}, \qquad (2\text{-}3a)$$

where

$$c_k = \frac{l_k^3}{3EJ}.$$

In the complex cases it is possible to find spring sags as sum of the displacement/movements, caused by separate forces, using the superposition principle of forces.

Contact group consists of several springs, which undergo of the process of the work of relay sagging/deflections of the specific sequence; therefore let us divide the work of the group into separate cell/elements, which correspond to the simplest operations above springs, and let us examine these cell/elements separately from each other.

a) spring sag, loaded by one force.

The construction of the contact groups of relay is usually assigned; therefore the distance of the points of application of force from the bearing edge, and also all points whose displacement/movement us can interest, to us it is known.

A quantity of operating points of the contact groups of relay is usually equal to three or four: A, C, D or A, B C and D (Fig. 2-4).

For the facilitation of the calculation of contact groups, let us compose system of equations, which mutually connect the amounts of the applied forces and the corresponding to them sagging/deflections of the operating points of springs.

Let us designate forces, applied at points A, B, C and D, respectively by F_a, F_b, F_c and F_d, but the

sagging/deflections in of these points, caused by the force F_a, applied at point A, respectively $y_{a(a)}$, $y_{b(a)}$, $y_{c(a)}$ and $y_{d(a)}$.

The sagging/deflections at the same points, caused by the force F_b, applied at point B of spring, let us designate by $y_{a(b)}$, $y_{b(b)}$, $y_{c(b)}$ and $y_{d(b)}$.

Thus, in our designations the first letter from below (index) indicates the point of the spring for which is determined the sagging/deflection, and the second letter, which stands in brackets, indicates the point at which is applied the force, which caused this sagging/deflection. The distances of points A, B, C and D from the bearing edge of spring (seal) let us designate by l_a, l_b, l_c and l_d.

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)

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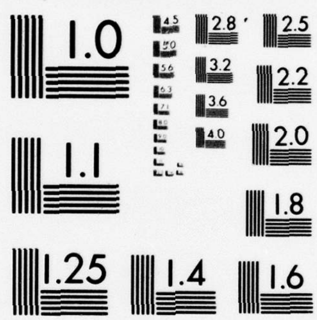

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

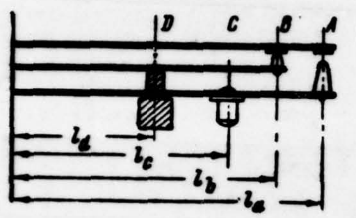

Fig. 2-4. Outline of contact group No of 11 relays of type 100.

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The displacement/movement of contact A of **the spring,** depicted in Fig. 2-5, caused by action of force F_a, applied at point A, it is possible to determine, **using** formula (2-2):

$$y_{a(a)} = \frac{F_a l_a^3}{3EJ} = F_a c_a. \qquad (2\text{-}4)$$

The displacement/movement this same of contact under the effect of force F_c, **of** the applied to the driving/moving plug spring **(at point C),** let us compute with the aid of formula **(2-3):**

$$y_{a(c)} = \frac{F_c l_c^2}{6EJ}(3l_a - l_c). \qquad (2\text{-}5)$$

Let us designate relation l_c to l_a by k_c; then $l_c = k_c l_a$. After substituting into formula (2-5) instead of l_c its value from last/latter expression, we will obtain:

$$y_{a(c)} = \frac{F_c k_c^2 l_a^3}{6EJ}(3l_a - k_c l_a) = = F_c c_a k_c^2 \frac{3-k_c}{2} = F_c c_m, \quad (2\text{-}5a)$$

where c_a - the flexibility of an entire spring and $c_m = c_a k_c^2 \frac{3-k_c}{2}$ - the flexibility of spring at point A, in reference to the force, applied at point C (the "mutual" flexibility). The flexibility of section of spring with length l_c is respectively equal to:

$$c_c = \frac{l_c^3}{3EJ} = \frac{k_c^3 l_a^3}{3EJ} = k_c^3 c_a.$$

Having substituted in equation (2-5a) instead of c_a its value from last/latter expression, we will obtain:

$$y_{a(c)} = \frac{c_c}{k_c^3} F_c k_c^2 \frac{3-k_c}{2} = y_c \frac{3-k_c}{2k_c} = F_c c_m, \quad (2\text{-}5b)$$

where

$$y_c = F_c c_c \quad \text{and} \quad c_m = c_c \frac{3-k_c}{2k_c} = c_a k_c^2 \frac{3-k_c}{2}.$$

In a similar manner we find expression for displacing the driving/moving plug of spring under the effect of the force F_a, applied to the contact:

$$y_{c(a)} = F_a c_a k_c^2 \frac{3-k_c}{2} = y_a \frac{k_c^2(3-k_c)}{2} = F_a c_m, \quad (2\text{-}5c)$$

where

$$y_a = F_a c_a.$$

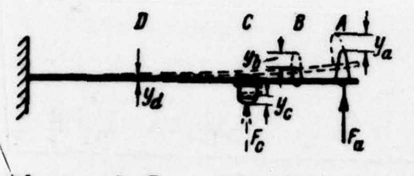

Fig. 2-5. Displacement/movement of contact spring under action of applied forces.

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The flexibility of the sections of springs by length l_b and l_d is equal to:

$$c_b = \frac{l_b^3}{3EJ} = k_b^3 c_a; \qquad c_d = \frac{l_d^3}{3EJ} = k_d^3 c_a;$$
$$c_{mb} = c_a k_b^2 \frac{3 - k_b}{2} = c_b \frac{3 - k_b}{2k_b}$$

and

$$c_{md} = c_a k_d^2 \frac{3 - k_d}{2} = c_d \frac{3 - k_d}{2k_d}.$$

The displacement/movement of contact A under the effect of force F_d, obviously, will be equal to:

$$y_{a(d)} = \frac{F_d l_d^2}{6EJ}(3l_a - l_d) = F_d c_a k_d^2 \frac{3 - k_d}{2} = y_d \frac{3 - k_d}{2k_d} = F_d c_{md}. \quad (2\text{-}6)$$

The displacement/movement of contact B, caused by the

action of force F_a, applied at point A of spring, let us determine with the aid of formula (2-1a):

$$y_{b(a)} = F_a c_a k_b^3 \frac{3-k_b}{2} = y_a k_b^3 \frac{3-k_b}{2} = F_a c_{mb}. \qquad (2\text{-}7)$$

In a similar manner we find expression for the sagging/deflections of points B, C and D of spring under the effect of forces F_a, F_b and F_c:

$$y_{b(b)} = F_b c_b = F_b c_a k_b^3; \qquad (2\text{-}8)$$

$$y_{b(c)} = F_c c_a k_c^3 \frac{3k_b - k_c}{2}; \qquad (2\text{-}9)$$

$$y_{c(c)} = F_c c_c = F_c c_a k_c^3; \qquad (2\text{-}10)$$

$$y_{d(a)} = F_a c_a k_d^3 \frac{3-k_d}{2} = F_a c_{md}; \qquad (2\text{-}11)$$

$$y_{d(b)} = F_b c_a k_d^3 \frac{3k_b - k_d}{2}; \qquad (2\text{-}12)$$

$$y_{d(c)} = F_c c_a k_d^3 \frac{3k_c - k_d}{2}; \qquad (2\text{-}13)$$

$$y_{d(d)} = F_d c_d = F_d c_a k_d^3. \qquad (2\text{-}14)$$

For relay of the type RKN, the backstop is arrange/located to the right of point C, since $l_d > l_c$; in this case

$$y_{d(c)} = \frac{F_c l_c^2}{6EJ}(3l_d - l_c) = F_c c_a k_c^3 \frac{3k_d - k_c}{2}. \qquad (2\text{-}15)$$

These equations give the dependence between the applied forces and the corresponding to them displacement/movements of the contact springs, loaded one layer and not having supplementary support.

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b) removal/taking spring from backstop.

For obtaining the specific pressure in contact, and also for a decrease in the bouncing of contacts during interrupting, the spring of the contact groups of relay they are usually regulated in such a way that in calm position they press to stop D with the specific force F_d.

In this case for the calculation of the springs of contact groups, it is necessary to use the method of the calculation of the beam, cantilevered and having inner bearing D to which this beam presses with force F_d.

External force at point D is not applied, the pressure of spring on backstop is reached because of the preliminary deformation of this spring during the adjustment of relay. Spring at calm state lie/rests horizontally and presses to backstop D; if we remove backstop, then because of preliminary deformation this spring will cave in will down and occupy the position, shown by dotted line in Fig. 2-6.

If we apply at point C some force F_c (directed upward), then at certain value of this force of pressure of spring on backstop D will be counterbalanced, and with a further increase in the force F_c spring will be removed from backstop.

Let us determine the amount of the force which must be applied to point C in order to remove/take springs from backstop.

The pressure of spring on backstop is usually unknown, and in instructions for the adjustment of relay under words "pressure on backstop" is implied force, which must be applied in the center of contact (point A or B) in order to remove/take this spring from backstop, i.e., instead of the force F_d is assigned the corresponding to it force F_a (or F_b).

Let us preliminarily find the pressure of spring on backstop F_d as function of the assigned force F_a (or F_b). For the solution of this problem, we will use method [Rayleigh, proposed for the solution of statically

indeterminate beams; we obtain:

$$F_{d1}=F_a\frac{3l_a-l_d}{2l_d}=F_a\frac{3-k_d}{2k_d}=F_a\frac{e_{md}}{c_d}. \quad (2\text{-}16)$$

Knowing value F_d, it is possible, using method mentioned above, to find the force F_c, which must be applied at point C (to bush) in order to remove/take spring from the backstop:

$$F_{c1}=F_d\frac{2k_d}{3k_c-k_d}. \quad (2\text{-}17)$$

Solving together equations (2-16) and (2-17), we find:

$$F_{c1}=F_a\frac{3-k_d}{3k_c-k_d}. \quad (2\text{-}18)$$

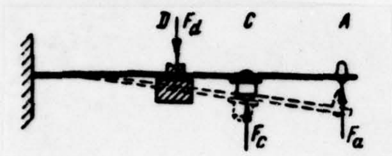

Fig. 2-6. Displacement/movement of contact spring during removal of backstop.

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If $l_d > l_c$ **(relay of the type RKN), then**

$$F_{c1} = F_d \frac{2k_d^2}{k_c^2(3k_d - k_c)} = F_a \frac{k_d^2(3 - k_d)}{k_c^2(3k_d - k_c)}. \quad (2\text{-}19)$$

For short springs the "pressure on backstop" is assigned at point B; therefore in a similar manner it is possible to write expression for the true pressure of spring **on backstop** F_d:

$$F_{d1} = F_b \frac{3k_b - k_d}{2k_d}. \quad (2\text{-}20)$$

Thus, using equations **(2-17), (2-18)** and **(2-19)** it is possible, knowing the "pressure of **spring** on backstop", to **determine** the amount of the **force** F_c, **which must** be applied to the driving/moving plug **of group** (at point C) in

order to remove/take spring from backstop D.

The torque/moment of removal/taking spring from backstop is characterized by the absence of its movement at point D; therefore, if springs were characterized by very high rigidity, then the torque/moment of removal/taking this spring from backstop would be characterized by the absence of the displacement not only of point D but also all remaining points of spring.

However, virtually we deal with elastic springs, and therefore during removal/taking from backstop will be motionless only point D of spring, the remaining points, which lie on section DA, will be moved under the action of the applied (counterbalancing) force F_c. The value of bending y_c, to which is displaced point C during removal/taking of spring from backstop D by the force F_c, applied at point C, it is equal to:

$$y_{c1} = y_{c(cd)} = \frac{F_c l_c^3}{3EJ}\left[1 - \frac{l_d}{4l_c^3}(3l_a - l_d)^2\right] = \\ = F_c c_a k_c^2\left[1 - \frac{k_d}{4k_c^3}(3k_c - k_d)^2\right]. \quad (2\text{-}21)$$

If $l_d > l_c$, then

$$y_{c1} = y_{c(cd)} = F_c k_c^2 c_a\left[1 - \frac{(3k_d - k_c)(3k_c - k_d)}{4k_d k_c}\right]. \quad (2\text{-}22)$$

The displacements of points A and B under the action of forces F_c, F_d and F_a, F_d during removal/taking of spring from backstop by forces F_c and F_a, correspondingly, are equal to:

$$y_{a1} = y_{a(cd)} = F_c c_a k_c^2 \left[\frac{3-k_c}{2} - \frac{k_d}{4k_c^2}(3k_c - k_d)(3-k_d)\right]; \quad (2\text{-}23)$$

$$y_{a1} = y_{a(ad)} = F_a c_a \left[1 - \frac{k_d(3-k_d)^2}{4}\right] = F_a c_a \left(1 - \frac{c_{md}^2}{c_a c_d}\right); \quad (2\text{-}24)$$

$$y_{b1} = y_{b(bd)} = F_b c_a k_b^3 \left[1 - \frac{k_d}{4k_b^3}(3k_b - k_d)^2\right]; \quad (2\text{-}25)$$

$$y_{b1} = y_{b(cd)} = F_c c_a k_c^2 \left[\frac{3k_b - k_c}{2} - \frac{k_d}{4k_c^2}(3k_b - k_d)(3k_c - k_d)\right]. \quad (2\text{-}26)$$

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If $l_d > l_c$, then

$$y_{a1} = y_{a(cd)} = F_a c_a k_c^2 \left[\frac{3-k_c}{2} - \frac{(3k_d - k_c)(3-k_d)}{4k_d}\right]; \quad (2\text{-}27)$$

$$y_{b1} = y_{b(cd)} = F_c c_a k_c^2 \left[\frac{3k_b - k_c}{2} - \frac{(3k_b - k_d)(3k_d - k_c)}{4k_d}\right]. \quad (2\text{-}28)$$

Using the given equations, it is possible to determine the values of forces and sagging/deflections at the fixed points of spring during removal/taking of the latter from backstop.

c) Removal/taking from the backstop of upper spring with the aid of lower spring.

During removal/taking from the support of upper contact spring with the aid of lower (movable) spring (Fig. 2-7) the sagging/deflections of both springs at point A, obviously, will be equal; in this case

$$y_{a(c)} + y_{a(a)} = y_{a(ad)}$$

or

$$\frac{F_c l_c^2}{6EJ_1}(3l_a - l_c) - \frac{F_a l_a^3}{3EJ_1} = \\ = \frac{F_a l_a^3}{3EJ_2}\left[1 - \frac{l_d}{4l_a^3}(3l_a - l_d)^2\right],$$

whence the amount of the force F_c, which must be applied at point C of lower spring for removal/taking with its aid from the backstop of upper spring, it will be equal to:

$$F_{c2} = F_a \frac{2l_a^3}{l_c^2(3l_a - l_c)} A = \frac{2F_a}{k_c^2(3 - k_c)} A, \qquad (2\text{-}29)$$

where

$$A = 1 + \frac{c'_a}{c_a}\left[1 - \frac{k_d(3 - k_d)^2}{4}\right]. \qquad (2\text{-}30)$$

In these formulas

$$c_a = \frac{l_a^3}{3EJ_1} \text{ and } c'_a = \frac{l_a^3}{3EJ_2},$$

where J_1 and J_2 - respectively the moments of the inertia

of lower (movable) and upper (motionless) springs. (for relays of the types RPN and RKN $J_1 = J_2$).

Displacement of point C of lower spring, during removal/taking with its aid of upper spring from backstop, is equal to:

$$y_{c2} = y_{c(ca)} = y_{c(c)} + y_{c(a)} = F_c c_a k_c^2 \left[1 - \frac{k_c}{4A}(3 - k_c)^2\right]. \quad (2\text{-}31)$$

The displacement of point A during removal/taking from the backstop of upper spring with the aid of lower spring will be equal to:

$$y_{a2} = y_{a(ca)} = y_{a(c)} - y_{a(a)} = F_c c_a k_c^2 \frac{3 - k_c}{2k_c}\left(1 - \frac{1}{A}\right) = y_c \frac{3 - k_c}{2k_c}\left(1 - \frac{1}{A}\right). \quad (2\text{-}32)$$

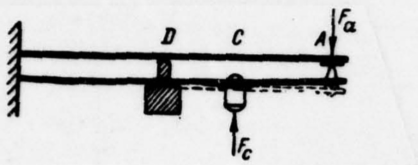

Fig. 2-7. Removal/taking upper contact spring from backstop.

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d) the combined sagging/deflection of both springs.

For providing the assigned pressure in contact, it is necessary that in running order of the relay among the backstop and the upper spring of group would be gap not less than 0.05 mm. (Value of this gap usually is within the limits from 0.05 to 0.3 mm).

For obtaining the gap at point D, it is necessary at point C of lower spring to apply supplementary force F_{c3}.

With the combined sagging/deflection of both springs,

their displacement at point A, obviously, will be equal:

$$y_{a(a)} = y_{a(ca)} \quad {}^{(1)}\text{или} \quad \frac{F_a l_a^3}{3EJ_2} = \frac{F_c l_c^2}{6EJ_1}(3l_a - l_c) - \frac{F_a l_a^3}{3EJ_1}.$$

Key: (1). or.

Hence the amount of supplementary force F_{c3} at point C will be equal to:

$$F_{c3} = F_a \frac{2}{k_c^2(3-k_c)}\left(1+\frac{c'_a}{c_a}\right) = F_a \frac{c_a + c'_a}{c_m}, \qquad (2\text{-}33)$$

where F_a - amount of supplementary force in the contact of relay at the combined sagging/deflection of both springs.

The supplementary displacement of point C with the combined sagging/deflection of both springs will be equal to:

$$y_{c3} = y_{c(ca)} = y_{c(c)} + y_{c(a)} =$$
$$= F_c c_a k_c^3\left[1 - \frac{k_c(3-k_c)^2}{4\left(1+\frac{c'_a}{c_a}\right)}\right] = F_a c_c \frac{1 - \frac{c_m^2}{c_a c_c} + \frac{c'_a}{c_a}}{1 + \frac{c'_a}{c_a}}. \qquad (2\text{-}34)$$

Air-gaps clearance between the upper spring and the contact of average at point B, and also between the upper spring and the backstop at point D, with the combined sagging/deflection of upper and lower springs, will be respectively equal to:

$$y_{b(a)} = F_a c_a k_b^2 \frac{3-k_b}{2} = F_c c_a k_b^2 k_c^2 \frac{(3-k_c)(3-k_b)}{4\left(1+\frac{c_a'}{c_a}\right)}; \qquad (2\text{-}35)$$

$$y_{d(a)} = F_a c_a k_d^2 \frac{3-k_d}{2} = F_c c_a k_c^2 k_d^2 \frac{(3-k_c)(3-k_d)}{4\left(1+\frac{c_a'}{c_a}\right)}. \qquad (2\text{-}36)$$

Displacement of upper spring at point A with the combined sagging/deflection of both springs

$$y_{a(a)} = F_a c_a' = F_c c_a k_c^2 \frac{3-k_c}{4} = y_c \frac{3-k_c}{4k_c}. \qquad (2\text{-}37)$$

In the case of the combined sagging/deflection of three springs

$$F_{c3} = F_a \frac{4}{k_c^2(3-k_c)}\left(1+\frac{c_a'}{c_a+c_a'}\right). \qquad (2\text{-}38)$$

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E) removal/taking upper or average spring from contact.

In contact groups for interrupting and switching in the calm position of relay, one of the springs rests on underlying contact, creating a pressure in the contact of rest (Fig. 2-8).

During removal/taking of movable (upper or average) spring from "motionless" contact, the sagging/deflections of both springs at point A, obviously, will be equal: in this case

$$y_{a(c)} + y_{a(a)} = y_{a(ad)}$$

or

$$\frac{F_c l_c^2}{6EJ_1}(3l_a - l_c) - \frac{F_a l_a^3}{3EJ_1} = \\ = \frac{F_a l_a^3}{3EJ_2}\left[1 - \frac{l_d}{4l_a^3}(3l_a - l_d)^2\right],$$

where J_1 and J_2 - respectively the moments of the inertia of upper (movable) and lower (" motionless") spring.

This equation completely coincides with analogous equation for the case of removal of upper spring with backstop; therefore for the calculation of cell/element "removal/taking of spring from contact" it is possible to **use equations (2-29), (2-31)** and **(2-32):**

$$F_{c4} = F_{c3} = \frac{2F_a}{k_c^2(3 - k_c)}A, \qquad y_{c4} = y_{c3} = F_c c_c k_c^3\left[1 - \frac{k_c}{4A}(3 - k_c)^2\right]$$

and

$$y_{a4} = y_{a3} = F_c c_c k_c^3 \frac{3 - k_c}{2k_c}\left(1 - \frac{1}{A}\right) = y_c \frac{3 - k_c}{2k_c}\left(1 - \frac{1}{A}\right).$$

If the underlying contact is motionless, then A = 1.

f) Removal/taking from the contact of upper spring with the aid of the third (lcwer) spring.

In contact groups for transient switching (with make-before-break contact) (Fig. 2-4) upper spring is remove/taken from the contact of average with the aid of the third (lower) spring.

During removal/taking of upper spring from the contact of average, the sagging/deflections of both these springs at point B, obviously, will be equal to:

$$y_{b(a)} + y_{b(b)} = y_{b(bd)}$$

or

$$\frac{F_a l_b^2}{6EJ_1}(3l_a - l_b) - \frac{F_b l_b^3}{3EJ_1} = \frac{F_b l_b^3}{3EJ_2}\left[1 - \frac{l_d}{4l_b^3}(3l_b - l_d)^2\right],$$

where J_1 is the moment of the inertia of movable (upper and lower) springs; J_2 is the moment of the inertia of "motionless" (middle) spring.

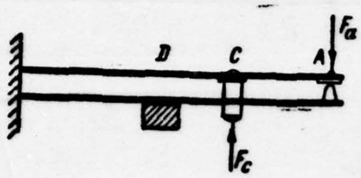

Fig. 2-8. Removal/taking upper spring from contact.

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We hence find the value of pressure in contact A during **removal/taking** of **upper** spring **from** contact B:

$$F_{ab} = F_b \frac{2k_b}{3-k_b} B = F_b \frac{c_b}{c_{mb}} B, \qquad (2\text{-}39)$$

where

$$B = 1 + \frac{c_a'}{c_a} - \frac{k_d c_a'}{4c_a k_b^2}(3k_b - k_d)^2. \qquad (2\text{-}40)$$

The sagging/deflection of upper spring at point A during its **removal/taking from** contact B will be equal to:

$$y_{a(c)} + y_{a(a)} = y_{a(ab)}$$

or

$$y_{ab} = y_{a(ab)} = F_a c_a \left[1 - \frac{k_b(3-k_b)^2}{4B}\right] = F_a c_a \left(1 - \frac{c_{mb}^2}{c_a c_b B}\right). \quad (2\text{-}41)$$

Since removal/taking upper spring from average is

conducted with the aid of lower (the third) spring, the sagging/deflections of upper and lower springs at point A will be equal; consequently,

$$y_{a(ab)} = y_{a(a)} + y_{a(b)}$$

or

$$\frac{F_c l_c^2}{6EJ_1}(3l_a - l_c) - \frac{F_a l_a^3}{3EJ_1} = \frac{F_a l_a^3}{3EJ_1}\left[1 - \frac{l_b(3l_a - l_b)^2}{4l_a^3 B}\right].$$

We hence find expression for the force F_c, which must be applied to lower spring at point C in order to remove/take upper spring from contact with the aid of the lower spring:

$$F_{cb} = F_a \frac{2}{k_c^2(3-k_c)}\left[2 - \frac{k_b(3-k_b)^2}{4B}\right]. \qquad (2\text{-}42)$$

Substituting for F_a its value from equation ~~(2-19)~~ (2-39), we find:

$$F_{cb} = F_b \frac{4k_b}{k_c^2(3-k_c)(3-k_b)}\left[2B - \frac{k_b(3-k_b)^2}{4}\right]. \qquad (2\text{-}43)$$

The displacement of point C during removal/taking of upper spring from contact B with the aid of lower spring will be equal to:

$$y_{cb} = y_{c(ca)} = y_{c(c)} + y_{c(a)} = F_c c_a k_c^2\left\{1 - \frac{k_c(3-k_c)^2}{4\left[2 - \frac{k_b(3-k_c)^2}{4B}\right]}\right\}. \qquad (2\text{-}44)$$

These equations make it possible to calculate the values of effort/forces and the corresponding to them

displacements of springs in the process of the transmission of effort/forces from the driving/moving plug to the contacts of group.

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With the aid of these equations, using the method of adding the action of forces, it is possible to calculate the extents of forces and movement of springs, which characterize the various stages of the work of contact group. After depositing these values consecutively on a graph, we obtain the mechanical characteristic of contact group (Fig. 2-1).

2-3. The approximate computation of the sagging/deflection of flat springs.

The given above formulas make it possible to accurately calculate the mechanical characteristics of contact groups. However, the calculation of the mechanical characteristics of complex contact groups with the aid of these formulas requires much time.

At the small length of spring as first approximation, it is possible to assume that with bending it remains straight line and only it is turned at the point of attachment. Then for the approximate computation of the characteristics of flat spring it is possible to obtain the simpler formula:

$$y=\frac{x}{l_k}\cdot\frac{Fl_k^3}{3EJ}=\frac{Fl_k^2}{3EJ}x. \qquad (2\text{-}45)$$

The second moment of area of flat spring of relatively neutral axis is equal to:

$$J=\frac{bh^3}{12}, \qquad (2\text{-}46a)$$

where b - width of spring and h - its thickness.

The second moment of area of wire spring is equal to:

$$J=\frac{\pi d^4}{64}, \qquad (2\text{-}46b)$$

where d - a diameter of the section of wire.

2-4. Calculation of the sagging/deflection of flat springs of trapezoidal form.

For the contact groups of the miniature/small relays, working in mobile units, and also for brushes and the contact groups of selectors frequent to be applied flat springs of triangular, more accurately trapezoidal form.

The contact springs of triangular shape with the identical length and the identical moment of inertia in critical section have approximately two times smaller mass and one and a half times smaller rigidity in comparison with right-angled springs. Therefore the relays, loaded by the contact springs of triangular form, require less than ampere-turns for function.

Furthermore, the large part of the mass of the spring of triangular form is concentrated near bearing edge, the free end/lead of this spring, carrying contact, has the smallest mass and therefore considerably less it is subjected to vibrations in work than in the springs of rectangular form.

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However, the contact springs of triangular form in practice cannot be used, since at the free end/lead of the spring must be fastened the contact, distance of center of which is the calculated length of the spring. Therefore are virtually applied the contact springs only of trapezoidal form.

The calculation of the springs of trapezoidal form is very complex. For simplification in the calculation, let us assume that the spring of trapezoidal form can be replaced by two springs - rectangular and triangular form (Fig. 2-9). Let us suppose that these springs are bent independently of each other under the action of two different forces, but they have in this case identical sagging/deflection [2-5].

For the spring of triangular form, the differential equation of elastic curve can be written in the following form:

$$EJ_x\frac{d^2y}{dx^2}=M_x, \qquad (2\text{-}47)$$

where J_x - the second moment of area at point x relative to z axis.

From the similarity of triangles, we find:

$$b_x = \frac{b_T(l-x)}{l}.$$

The second moment of area at point x is equal to:

$$J_x = \frac{b_T h^3}{12} - \frac{b_T h^3 x}{12l} = J_T\left(1 - \frac{x}{l}\right), \qquad (2\text{-}48)$$

where

$$J_T = \frac{b_T h^3}{12}.$$

Substituting instead of J_x and M_x their value, we will obtain:

$$\frac{d^2y}{dx^2} = \frac{P_T(l-x)}{EJ_T\left(1-\frac{x}{l}\right)} = \frac{P_T l}{EJ_T}. \qquad (2\text{-}49)$$

By integrating twice the equation of elastic curve, we find the dependence between amount of deflection of the spring of triangular form in any section and the applied force:

$$y = \frac{P_T l x^2}{2EJ_T}. \qquad (2\text{-}50)$$

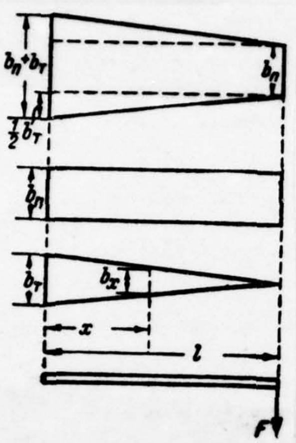

Fig. 2-9. Springs of trapezoidal and triangular form.

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Amount of deflection of the end/lead of the spring at the point of application of force is equal to:

$$y_T = \frac{F_T l^3}{2EJ_T}. \qquad (2\text{-}51)$$

From equation (2-50) we find expression for the force F_T, which must be applied at the end/lead of the spring of triangular form for obtaining of sagging/deflection, equal y:

$$F_T = \frac{2EJ_T y}{l^3}. \qquad (2\text{-}52)$$

The amount of the force $F_{\text{п}}$, which must be applied at the end/lead of right-angled spring for obtaining the equal sagging/deflection y, let us determine from expression (2-1):

$$F_{\text{п}} = \frac{6EJ_{\text{п}}y}{x^2(3l - x)},$$

where

$$J_{\text{п}} = \frac{b_{\text{п}}h^3}{12}.$$

Then the amount of the force which must be applied at the end/lead of the spring of the trapezcidal form, comprised of two springs of triangular and rectangular form, cbviously, it will be equal to the sum cf forces $F_{\text{т}}$ and $F_{\text{п}}$; we have:

$$F = F_{\text{т}} + F_{\text{п}} = \frac{2EJ_{\text{т}}y}{lx^2} + \frac{6EJ_{\text{п}}y}{x^2(3l - x)} = \frac{2Ey}{x^2}\left(\frac{J_{\text{т}}}{l} + \frac{3J_{\text{п}}}{3l - x}\right), \quad (2\text{-}53)$$

whence we find expression for the spring sag of trapezoidal form in any section, which is located between the place of seal and the point of application of force:

$$y = \frac{Fx^2}{2E\left(\frac{J_{\text{т}}}{l} + \frac{3J_{\text{п}}}{3l - x}\right)} = \frac{Fx^2l(3l - x)}{2E\left[(3l - x)J_{\text{т}} + 3lJ_{\text{п}}\right]}. \quad (2\text{-}54)$$

Amount of deflection of the end/lead of the spring of trapezoidal form (with x = l) will be equal to:

$$y = \frac{Fl^3}{(2J_{\text{т}} + 3J_{\text{п}})E}. \quad (2\text{-}55)$$

The error, which give these approximation formulas, does not exceed 4o/o.

2-5. Calculation of the flat/plane bent springs.

In miniature/small instruments as a result of faults of places, usually it is necessary to apply the flat/plane bent springs. Figures 2-10 shows the outlines of the most frequently used flat/plane bent springs.

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These springs consist of the direct/straight and bent in circumference sections; therefore the sagging/deflection of the bent springs is located as sum of the sagging of these sections of the point of application of force. If the ratio of the thickness of spring to a radius of the rounding of the bent part is less than 0.6, then the value of additional shear stresses can be disregarded.

According to Castigliano theorem the spring sag y in the direction of the applied load P is equal to derivative

of work A_y on load [2-6].

The work

$$A_y = \frac{1}{2EJ} \int_{s=0}^{l} M^2 ds,$$

where M is the bending moment, l - the overall length of spring and ds - infinitesimal element of length of spring.

Spring sag in the direction of the applied load

$$y = \frac{\partial A_y}{\partial F} = \frac{1}{2EJ} \frac{\partial}{\partial F} \int_{s=0}^{l} M^2 ds$$

or

$$y = \frac{1}{EJ} \int_{s=0}^{l} M \frac{\partial M}{\partial F} ds. \qquad (2-56)$$

The sagging/deflection of the bent spring, depicted in Fig. 2-10a, is equal to the sum of the sagging of the direct/straight section y_1 and of the rounded section y_2: $y = y_1 + y_2$.

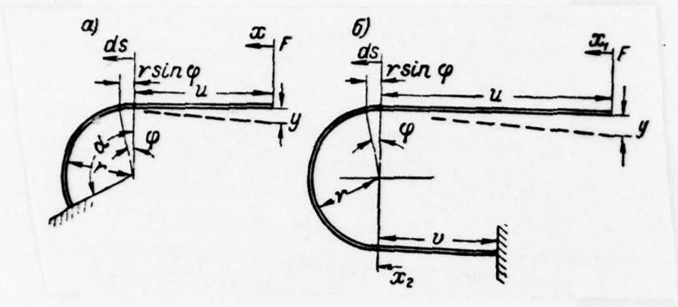

Fig. 2-10. Flat/plane bent **springs.**

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According to formula (2-56) we find for the direct/straight section of the spring:

$$y_1 = \frac{1}{EJ}\int\limits_{x=0}^{x=u} Fx^2\,dx = \frac{Fu^3}{3EJ}$$

and **for the rounded section of the spring**

$$y_2 = \frac{1}{EJ}\int\limits_{\varphi=0}^{\varphi=\alpha} F(u + r\sin\varphi^2)\,r\,d\varphi =$$
$$= \frac{Fr}{EJ}\left[\left(u^2 + \frac{r^2}{2}\right)\alpha + 2ru\,(1-\cos\alpha) - \frac{r^2}{4}\sin 2\alpha\right],$$

where r is a radius of the rounding of **the bent** part of the spring, ϕ is alternate angle, α - the central angle of bent part and u - the length of the straight portion of spring.

Consequently, spring sag (Fig. 2-10a) at the point of application of force will be equal to:

$$y = \frac{F}{EJ}\left[\frac{u^3}{3} + \left(u^2 r + \frac{r^3}{2}\right)\alpha + 2ur^2(1 - \cos\alpha) - \frac{r^3}{4}\sin 2\alpha\right]. \quad (2\text{-}57)$$

If the value of the central angle of the bent part of the spring α = 90°, then

$$y = \frac{F}{EJ}\left[\frac{u^3}{3} + \pi\left(u^2 r + \frac{r^3}{2}\right) + 2ur^2\right]. \quad (2\text{-}57a)$$

In a similar manner is determined expression for the sagging/deflection of the bent spring, depicted in Fig. 2-10b; we have:

$$y = \frac{1}{EJ}\left[\int\limits_{x=0}^{x=u} Fx_1^2\,dx_1 + \int\limits_{\varphi=0}^{\varphi=\pi} F(u + r\sin\varphi)^2 r\,d\varphi + \int\limits_{x_2=0}^{x_2=v} F(u + x_2)^2\,dx_2\right] = \frac{F}{EJ}\left(\frac{u^3+v^3}{3} + \pi ru^2 + 4r^2u + \frac{\pi r^3}{2} + u^2v - uv^2\right), \quad (2\text{-}58)$$

where v - the length of the lower rectangular section of spring.

If value v is equal to zero, then

$$y = \frac{F}{EJ}\left(\frac{u^3}{3} + \pi ru^2 + 4r^2u + \frac{\pi r^3}{2}\right). \quad (2\text{-}58a)$$

The greatest bending moment occurs in the middle of the rounded part of the spring:

$$M_{\text{макс}} = F(u + r). \quad (2\text{-}59)$$

2-6. Calculation of the mechanical characteristics of standard contact groups.

Analytical calculation of the mechanical characteristics of contact groups is connected with very cumbersome calculations; however, for standard contact groups calculation can be considerably simplified, if we preliminarily calculate a series of the numerical coefficients, which depend on geometric dimensions and the material of contact springs.

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Table 2-1. On the calculation of the mechanical characteristics of standard relays.

	(1) Реле типа РПН			(1) Реле типа РКН	
	(2) Толщина пружин			(2) Толщина пружин	
	$h = 0{,}45$ *мм*	$h = 0{,}5$ *мм*	$h = 0{,}55$ *мм*	$h = 0{,}3$ *мм*	$h = 0{,}35$ *мм*
(3) I. Прогибы пружины в различных точках					
$y_{a(a)}$	$0{,}421 \cdot F_a$	$0{,}308 \cdot F_a$	$0{,}232 \cdot F_a$	$0{,}1565 \cdot F_a$	$0{,}0984 \cdot F_a$
$y_{a(b)}$	$0{,}390 \cdot F_b$	$0{,}286 \cdot F_b$	$0{,}215 \cdot F_b$	$0{,}1311 \cdot F_b$	$0{,}0825 \cdot F_b$
$y_{a(c)}$	$0{,}312 \cdot F_c$	$0{,}228 \cdot F_c$	$0{,}172 \cdot F_c$	$0{,}0851 \cdot F_c$	$0{,}0536 \cdot F_c$
$y_{a(d)}$	$0{,}278 \cdot F_d$	$0{,}204 \cdot F_d$	$0{,}154 \cdot F_d$	$0{,}1131 \cdot F_d$	$0{,}0712 \cdot F_d$
$y_{b(a)}$	$0{,}390 \cdot F_a$	$0{,}286 \cdot F_a$	$0{,}215 \cdot F_a$	$0{,}1311 \cdot F_a$	$0{,}0825 \cdot F_a$
$y_{b(b)}$	$0{,}362 \cdot F_b$	$0{,}265 \cdot F_b$	$0{,}200 \cdot F_b$	$0{,}1110 \cdot F_b$	$0{,}0698 \cdot F_b$
$y_{b(c)}$	$0{,}291 \cdot F_c$	$0{,}213 \cdot F_c$	$0{,}160 \cdot F_c$	$0{,}0732 \cdot F_c$	$0{,}0461 \cdot F_c$
$y_{b(d)}$	$0{,}261 \cdot F_d$	$0{,}191 \cdot F_d$	$0{,}144 \cdot F_d$	$0{,}0961 \cdot F_d$	$0{,}0606 \cdot F_d$
$y_{c(a)}$	$0{,}312 \cdot F_a$	$0{,}228 \cdot F_a$	$0{,}172 \cdot F_a$	$0{,}0851 \cdot F_a$	$0{,}0536 \cdot F_a$
$y_{c(b)}$	$0{,}291 \cdot F_b$	$0{,}213 \cdot F_b$	$0{,}160 \cdot F_b$	$0{,}0732 \cdot F_b$	$0{,}0461 \cdot F_b$
$y_{c(c)}$	$0{,}236 \cdot F_c$	$0{,}173 \cdot F_c$	$0{,}130 \cdot F_c$	$0{,}0505 \cdot F_c$	$0{,}0318 \cdot F_c$
$y_{c(d)}$	$0{,}213 \cdot F_d$	$0{,}156 \cdot F_d$	$0{,}117 \cdot F_d$	$0{,}0645 \cdot F_d$	$0{,}0406 \cdot F_d$
$y_{d(a)}$	$0{,}278 \cdot F_a$	$0{,}204 \cdot F_a$	$0{,}154 \cdot F_a$	$0{,}1131 \cdot F_a$	$0{,}0712 \cdot F_a$
$y_{d(b)}$	$0{,}261 \cdot F_b$	$0{,}191 \cdot F_b$	$0{,}144 \cdot F_b$	$0{,}0961 \cdot F_b$	$0{,}0606 \cdot F_b$
$y_{d(c)}$	$0{,}213 \cdot F_c$	$0{,}156 \cdot F_c$	$0{,}117 \cdot F_c$	$0{,}0645 \cdot F_c$	$0{,}0406 \cdot F_c$
$y_{d(d)}$	$0{,}193 \cdot F_d$	$0{,}141 \cdot F_d$	$0{,}106 \cdot F_d$	$0{,}0832 \cdot F_d$	$0{,}0530 \cdot F_d$
(4) II. Снятие нижней пружины с упора					
F_{c1}	$1{,}307 \cdot F_{a1}$	—	—	$1{,}755 \cdot F_{a1}$	—
F_{c1}	$0{,}905 \cdot F_{d1}$	—	—	$1{,}305 \cdot F_{d1}$	—
F_{d1}	$1{,}445 \cdot F_{a1}$	—	—	$1{,}345 \cdot F_{a1}$	—
F_{d1}	$1{,}350 \cdot F_{b1}$	—	—	$1{,}145 \cdot F_{b1}$	—
y_{c1}	$0{,}0008 \cdot F_{c1}$	$0{,}0006 \cdot F_{c1}$	$0{,}00043 \cdot F_{c1}$	$0{,}0011 \cdot F_{c1}$	$0{,}0007 \cdot F_{c1}$
y_{a1}	$0{,}0035 \cdot F_{c1}$	$0{,}0026 \cdot F_{c1}$	$0{,}00196 \cdot F_{c1}$	$-0{,}0014 \cdot F_{c1}$	$-0{,}0009 \cdot F_{c1}$
y_{b1}	$0{,}0096 \cdot F_{b1}$	$0{,}0070 \cdot F_{b1}$	$0{,}0053 \cdot F_{b1}$	$0{,}0006 \cdot F_{b1}$	$0{,}0004 \cdot F_{b1}$
y_{b1}	$0{,}0027 \cdot F_{c1}$	$0{,}0020 \cdot F_{c1}$	$0{,}0015 \cdot F_{c1}$	$-0{,}0006 \cdot F_{c1}$	$-0{,}0004 \cdot F_{c1}$
(5) III. Снятие с упора верхней пружины с помощью нижней пружины					
F_{c2}	$1{,}410 \cdot F_{a2}$	—	—	$1{,}880 \cdot F_{a2}$	—
y_{c2}	$0{,}0150 \cdot F_{c2}$	$0{,}0110 \cdot F_{c2}$	$0{,}0083 \cdot F_{c2}$	$0{,}0054 \cdot F_{c2}$	$0{,}0034 \cdot F_{c2}$
y_{a2}	$0{,}0177 \cdot F_{a2}$	$0{,}0130 \cdot F_{a2}$	$0{,}0098 \cdot F_{a2}$	$0{,}0042 \cdot F_{a2}$	$0{,}0026 \cdot F_{a2}$
y_{a2}	$0{,}0126 \cdot F_{c2}$	$0{,}0092 \cdot F_{c2}$	$0{,}0069 \cdot F_{c2}$	$0{,}0022 \cdot F_{c2}$	$0{,}0014 \cdot F_{c2}$
(6) IV. Совместный прогиб обеих пружин					
F_{c3}	$2{,}70 \cdot F_{a3}$	—	—	$3{,}67 \cdot F_{a3}$	—
F_{a3}	$0{,}3705 \cdot F_{c3}$	—	—	$0{,}272 \cdot F_{c3}$	—
y_{c3}	$0{,}121 \cdot F_{c3}$	$0{,}0837 \cdot F_{c3}$	$0{,}0667 \cdot F_{c3}$	$0{,}0272 \cdot F_{c3}$	$0{,}0172 \cdot F_{c3}$
y_{b3}	$0{,}145 \cdot F_{c3}$	$0{,}106 \cdot F_{c3}$	$0{,}0798 \cdot F_{c3}$	$0{,}0358 \cdot F_{c3}$	$0{,}0225 \cdot F_{c3}$
y_{d3}	$0{,}103 \cdot F_{c3}$	$0{,}0756 \cdot F_{c3}$	$0{,}0569 \cdot F_{c3}$	$0{,}0308 \cdot F_{c3}$	$0{,}0194 \cdot F_{c3}$
y_{a3}	$0{,}156 \cdot F_{c3}$	$0{,}117 \cdot F_{c3}$	$0{,}086 \cdot F_{c3}$	$0{,}0426 \cdot F_{c3}$	$0{,}0268 \cdot F_{c3}$
(7) V. Снятие верхней или средней пружины с контакта					
F_{c4}	$1{,}410 \cdot F_{a4}$	—	—	$1{,}880 \cdot F_{a4}$	—
y_{c4}	$0{,}0150 \cdot F_{c4}$	$0{,}0110 \cdot F_{c4}$	$0{,}0083 \cdot F_{c4}$	$0{,}0054 \cdot F_{c4}$	$0{,}0034 \cdot F_{c4}$
y_{a4}	$0{,}0177 \cdot F_{a4}$	$0{,}0130 \cdot F_{a4}$	$0{,}0098 \cdot F_{a4}$	$0{,}0042 \cdot F_{a4}$	$0{,}0026 \cdot F_{a4}$
y_{a4}	$0{,}0126 \cdot F_{c4}$	$0{,}0092 \cdot F_{c4}$	$0{,}0069 \cdot F_{c4}$	$0{,}0022 \cdot F_{c4}$	$0{,}0014 \cdot F_{c4}$
(8) VI. Снятие с контакта верхней пружины с помощью третьей (нижней) пружины.					
F_{c5}	$1{,}389 \cdot F_{a5}$	—	—	$1{,}863 \cdot F_{a5}$	—
F_{a5}	$0{,}955 \cdot F_{b5}$	—	—	$0{,}851 \cdot F_{b5}$	—
F_{c5}	$1{,}326 \cdot F_{b5}$	—	—	$1{,}585 \cdot F_{b5}$	—
y_{c4}	$0{,}0122 \cdot F_{c5}$	$0{,}0089 \cdot F_{c5}$	$0{,}0067 \cdot F_{c5}$	$0{,}0048 \cdot F_{c5}$	$0{,}0030 \cdot F_{c5}$
y_{a5}	$0{,}0122 \cdot F_{a5}$	$0{,}0089 \cdot F_{a5}$	$0{,}0067 \cdot F_{a5}$	$0{,}0024 \cdot F_{a5}$	$0{,}0015 \cdot F_{a5}$
(9) VII. Размеры пружин					
l_a	73,9 *мм*	—	—	37,0 *мм*	—
l_b	70,3 »	—	—	33,0 »	—
l_c	61,0 »	—	—	25,4 »	—
l_d	57,0 »	—	—	30,1 »	—
b	3,5 »	—	—	4,0 »	—
J	0,0266 *мм*^{4}	0,0365 *мм*^{4}	0,0485 *мм*^{4}	0,009 *мм*^{4}	0,0143 *мм*^{4}

Key: (1). Relays of the type. (2). Thickness of springs. (3). Spring sags at different points. (4). Removal/taking lower spring from backstop. (5). Removal/taking from the backstop of upper spring with the aid of lower spring. (6). Combined sagging/deflection of both springs. (7). Removal/taking upper or average spring from contact. (8). Removal/taking from the contact of upper spring with the aid of the third (lower) spring. (9). Size/dimensions of springs.

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Effect of a change in the width of spring of end/lead, and also friction we disregard. Furthermore, let us consider that the pressure of spring on backstop is concentrated in its center.

Springs of the contact groups of relay they are manufactured from extra-hard argentan, which has on the average **modulus of the elasticity**

$$E = 1{,}2 \cdot 10^{6}\ (1)\ кГ/см^2 = 12 \cdot 10^{6}\ Г/(2).$$

Key: (1). kgf/cm². (2). g/mm².

The width of the contact springs of relay of the type RPN is equal to 3.5 mm, thickness their 0.5 mm. Moment of the inertia of spring of relay of the type RPN

$$J = \frac{3{,}5 \cdot 0{,}5^3}{12} = 0{,}0364 \text{ мм}^4.$$

The distance of point A from bearing edge is equal to 73.9 mm, point C it is equal to 61 mm and point D it is equal to 57 mm.

Substituting in equation (2-4) these values, we find the dependence between force and sagging/deflection in point A for the springs of relay of the type RPN in the following form:

$$y_{a(a)} = F_a c_a = F_a \frac{73{,}9^3}{3 \cdot 12 \cdot 10^3 \cdot 0{,}0364} = 0{,}308 F_a,$$

where $y_{a(a)}$ - sagging/deflection into mm, expressed by force F_a at point A of spring, F_a - force, applied at point A, in grams, c_a = 0.308 - the flexibility of an entire spring.

Substituting in remaining equations for E, J, l_a, l_b, l_c and l_d their value, we obtain the values of the flexibility of the springs which considerably facilitate the calculation of the mechanical characteristics of the contact groups of relay of the type RPN.

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Table 2-1 gives corrected values of the flexibility of springs for the relay of types RPN and RKN.

For bringing the displacement of the driving/moving plug to corresponding course of armature, it is necessary the extent of this movement y_c to multiply by the relation of the arms of armature and bridge. For relay of the type RPN, this sense is equal to:

$$\frac{75,5}{68} = 1,11.$$

Using the given above coefficients, it is possible to construct mechanical characteristics almost for all contact groups of the relay of types RPN and RKN during any adjustment of these groups.

2-7. Calculation of the mechanical characteristic of helical cylindrical spring.

The dependence between the elongation of the helical cylindrical spring of round cross-section y (Fig. 2-11) and the applied force F is expressed by the following formula:

$$y = \frac{F 2\pi r^3 n}{G J_p}, \qquad (2\text{-}60)$$

where F - strain in kgf; r is the mean radius of the turns of spring in mm; n is a turn number of spring; G - modulus of elasticity of shearing in kg/mm².

The polar moment of inertia for the wire of the round cross-section

$$J_p = \frac{\pi d^4}{32}, \qquad (2\text{-}61)$$

where d is a wire diameter in mm.

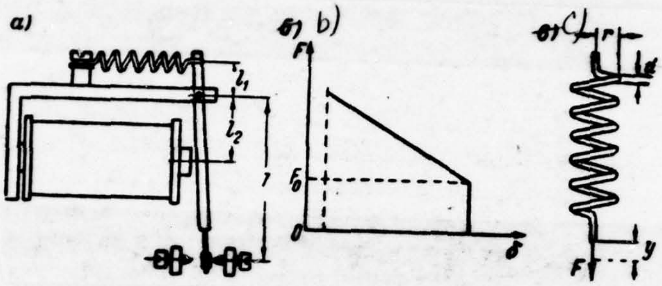

Fig. 2-11. Outline of relay with helical return spring (a): mechanical characteristic of relay with coil spring (b); outline of coil spring (c).

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Consequently, the mechanical characteristic of the coil spring of round cross-section will be expressed as follows:

$$F = \frac{Gd^4}{64nr^3} y = iy, \qquad (2\text{-}62)$$

where i is a spring constant.

Figures 2-11a shows relay with helical return spring. For the creation of contact pressure F_K in calm position, the spring usually has the initial tension

$$F_0 = F_K \frac{l}{l_1}.$$

In operating position the spring is dilate/extended, and reacting force of spring will be equal to:

$$F_1 = F_0 + iy = F_к \frac{l}{l_1} + i \frac{\Delta l_1}{l},$$

where Δ is a distance between contacts.

After giving this force to the course of armature, we will obtain the equation of the mechanical characteristic of this relay (Fig. 2-11b):

$$F_м = F_к \frac{l}{l_2} + i\Delta \frac{l_1^2}{ll_2}. \qquad (2\text{-}63)$$

With light loads it is necessary to also consider gravity force component of the movable system of relay.

2.8. Example.

Let us construct analytically the mechanical characteristic of the closing contact group a of relay of the type RPN (Fig. 2-12).

Group a has the following adjustment: the pressure of

lower spring on backstop, measured on contact A 13-17 gf Thickness of springs 0.50 mm. Pressure in contact 20-25 gf Distance between the contacts 0.50 mm. Relation of the arms of armature and bridge a/b = 1.11. Course of the armature of relay 1.1 mm, the freewheeling escapement 0.10 mm.

Calculation is divided into four independent cell/elements.

a) Removal/taking the lower spring of group from backstop.

Mean pressure of lower spring on backstop, measured at point A, we take equal to 15 gf

The force which must be applied to the blade (bushing) of group (point C) in order to remove/take spring from backstop according to equation (2-18) and table 2-1, in which corrected values of flexibility, calculated according to this equation, it will be equal to:

$$F_{c1} = 1{,}307 \cdot F_a = 1{,}307 \cdot 15 = 19{,}6 \text{ gf}.$$

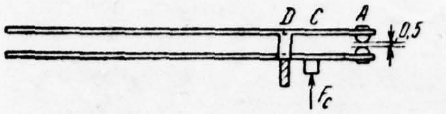

Fig. 2-12. Outline of contact group a (with circuit closing contact) of relay of type RPN.

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The displacement of point C in the process of relieving the spring from backstop, caused by action F_c and F_d, according to equation (2-21) and Tabl. of 2-1, will be:

$$y_{c1} = 0{,}0006 \cdot F_c = 0{,}0006 \cdot 19{,}6 = 0{,}012 \text{ мм.}$$

Armature travel of relay in the process of relieving the spring from the backstop

$$\delta_1 = y_{c1}\frac{a}{b} = 0{,}012 \cdot 1{,}11 = 0{,}0133 \text{ мм.}$$

Thus, the process of relieving the lower spring from backstop is determined by the following values:

$$F_{c1} = 19{,}6\ \Gamma; \qquad \delta_1 = 0{,}013 \text{ мм.}$$

b) the bending of lower spring to the contact of its contact with the contact of upper spring.

After removal/taking of lower spring from backstop, it is necessary to apply at point C some secondary force F_c in order to bend this spring to the contact between themselves of the contacts of both springs. Force F_c can be calculated, if is known the distance between the contacts which must be locked.

In the calm state of group, the distance between contacts Δ, according to condition, is equal to 0.50 mm, but after removal/taking of lower spring from backstop, this distance will be somewhat less.

The displacement of contact A of lower spring with removal from backstop let us compute with the aid of equation (2-23) and table 2-1:

$$y_{a1} = 0{,}0026 \cdot 15 = 0{,}039 \text{ мм.}$$

The distance between contacts after removal/taking of lower spring from backstop, will be equal to:

$$\Delta - y_{a1} = 0{,}50 - 0{,}039 = 0{,}461 \text{ мм.}$$

In order to move the contact of lower spring for distance 0.461 mm, it is necessary at point C of this spring to apply the force F_c, whose value can be calculated, using equation (2-5) and table 2-1:

$$F_c = \frac{y_{a(c)}}{0{,}228} = \frac{\Delta - y_{a1}}{0{,}228} = 2{,}02 \text{ gf}$$

Displacement of point C with the bending of lower spring to the contact of its contact with the contact of upper spring let us compute with the aid of equation (2-10) and table 2-1: we obtain:

$$y_c = 0{,}173 \cdot F_c = 0{,}173 \cdot 2{,}02 = 0{,}35 \text{ мм}.$$

The corresponding armature travel of relay will be equal

$$\delta_2 = y_c \frac{a}{b} = 0{,}35 \cdot 1{,}11 = 0{,}39 \text{ мм}.$$

c) Removal/taking from the backstop of upper spring with the aid of lower spring.

The pressure of upper spring on backstop, measured at

point A, is approximately equal tc pressure in the contact whose value must be within the limits from 20 to 25 gf.

The value of the pressure cf upper spring on backstop at point A we take 21 gf.

The amount of the force F_{c2}, which must be applied at point C of lower spring in order to remcve/take from backstop with its aid the upper spring

$$F_{c2} = 1{,}410 \cdot F_a = 1{,}410 \cdot 21 = 29{,}6 \text{ gf.}$$

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Displacement of the bush of contact group during removal/taking from the backstop of the upper spring

$$y_{c2} = 0{,}0110 \cdot F_{c2} = 0{,}0110 \cdot 29{,}6 = 0{,}325 \text{ мм.}$$

Corresponding displacement of the armature of relay will be:

$$\delta_2 = 0{,}325 \cdot 1{,}11 = 0{,}36 \text{ мм.}$$

D) The combined sagging/deflection cf both springs.

The complete course of the armature of the relay should be equal to 1.1 mm, therefore, with the combined sagging/deflection of both springs the displacement of bush must not exceed

$$\delta_{c} = 1{,}1 - (0{,}013 + 0{,}39 + 0{,}36 + 0{,}1) = 1{,}1 - 0{,}863 = 0{,}237 \text{ мм}$$

or

$$y_{cs} = \frac{0{,}237}{1{,}11} = 0{,}214 \text{ мм}.$$

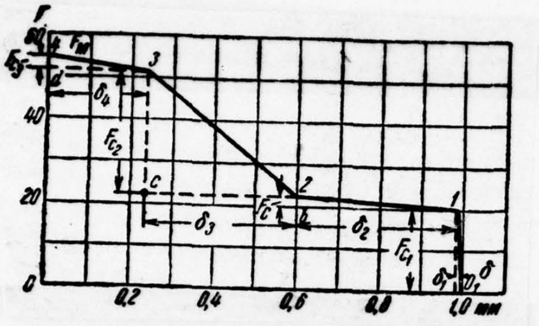

Fig. 2-13. Mechanical characteristic of contact group a of relay of type RPN.

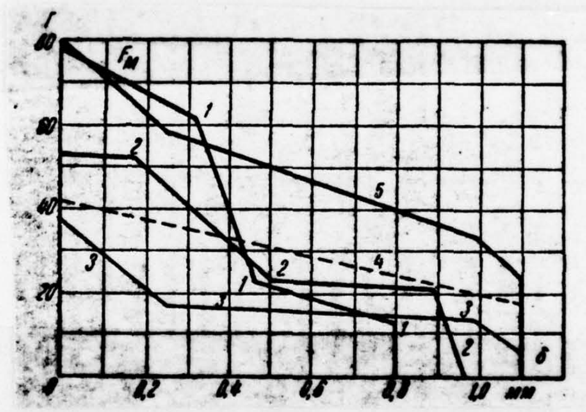

Fig. 2-14. Mechanical characteristics of contact groups with closing of contacts for different types of relay. 1 - type RKN; 2 - type RPN; 3 - type RKM-1; 4 - return spring of the armature of relay of type RKM-1; 5 - type rmk-1 with the return spring of armature.

[Γ = g]

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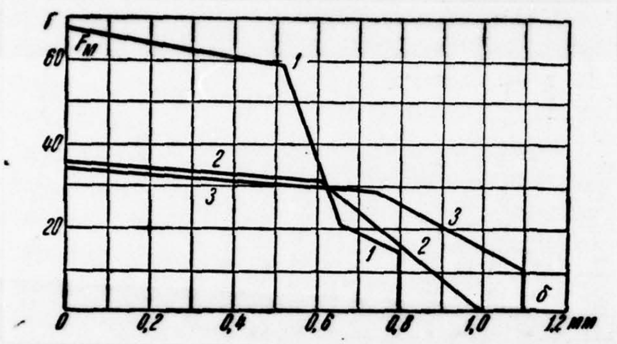
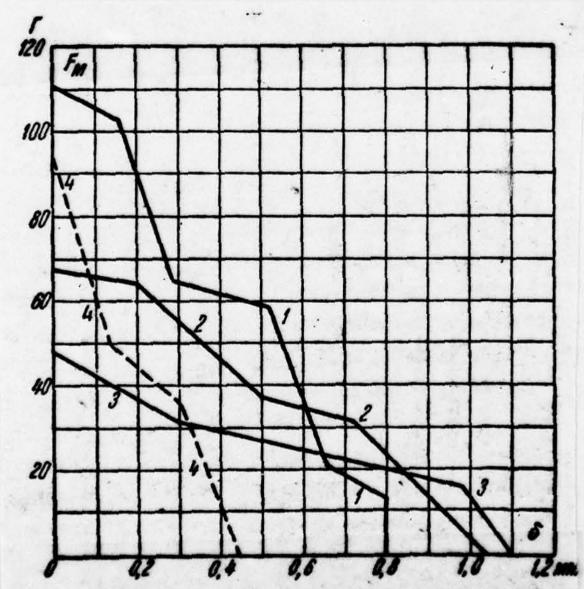


[Г = g]

Fig. 2-15. Mechanical characteristics of contact groups with breaking contact for different types of relay. 1 - type RKN; 2 - type RPN; 3 - type RKM-1.



[Г = g]

Fig. 2-16. Mechanical characteristics of contact groups with stud switches for different types of relay. 1 - type RKN; 2 - type RPN; 3 - type RMK-1; 4 - type RS-13.

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On the other hand, according to equation (2-31) and table 2-1,

$$y_{c4} = 0{,}0887 \cdot F_{c4},$$

whence we find the amount of the supplementary force F_{c3}, which must be applied at point C for its displacement on 0.214 mm:

$$F_{c3} = \frac{y_{c4}}{0{,}0887} = \frac{0{,}214}{0{,}0887} = 2{,}41 \text{ gf}$$

An increase of the pressure in contact F_a with the combined sagging/deflection of both springs, according to equation (2-33) and table 2-1, comprises:

$$F_{a3} = 0{,}3705 \cdot F_{c3} = 0{,}3705 \cdot 2{,}41 = 0{,}92 \text{ gf}$$

Consequently, the total pressure in the contact of the relay

$$F_{\kappa} = 21 + 0{,}92 = 22{,}02 \text{ gf}$$

Air-gap clearance between the upper spring and the backstop in this case is equal to:

$$y_{d3} = 0{,}0756 \cdot F_{c3} = 0{,}0756 \cdot 2{,}41 = 0{,}182 \text{ мм}.$$

Thus, the combined sagging/deflection cf both springs of group is determined by the following values:

$$F_{c2} = 2{,}41\ \Gamma, \qquad \delta_4 = 0{,}237\ \text{мм}.$$

Pressure of group on **bushing of** armature in the pulled position of the **latter**

$$F_c = 19{,}6 + 2{,}02 + 29{,}6 + 2{,}41 \approx 53{,}6\ gf.$$

the **mechanical** characteristic of group a it is shown in Fig. 2-13.

For a comparison Fig. 2-14, 2-15 and 2-16 give the mechanical characteristics of contact groups with closing, who break and by the changing over (reversing) contacts of the relay of types RPN, RKN and RKM-1.

Chapter Three.

CALCULATION OF SPRINGS.

3-1. General information.

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The fundamental characteristics of spring alloys, which determine the reliability of the operation of contact springs, are: elastic limit, relaxation resistance and endurance limit (fatigue).

Stress relaxation is the process of consequence, which is expressed in a change (decrease in time) in the stresses of the elastic deformed metal as a result of the transition of elastic deformation to plastic with a constant

value of overall strain. Relaxation phenomena occur as a result of the course of shift-dislocation and diffusion-dislocation processes in metal. Therefore the structure of alloys for springs must provide high resistor/resistance to small plastic deformations.

The value of stress relaxation and the endurance limit of alloys for springs depend on elastic limit.

For providing the reliable work of springs, stress relaxation must not exceed 10o/o with stresses of approximately 40 kg/mm^2.

The direct/straight elastic after-effect of metals is developed in the course of time in the supplementary deformation of material under the action of elastic stress. In this case, the deformation rate falls in the course of time, and deformation itself approaches certain limiting value. This process is characterized by from the known phenomenon of creep only amount of deformation and the degree of its reversibility (at elastic after-effect reversibility considerably more). Reverse/inverse elastic after-effect consists in the gradual removal/taking deformation mentioned above of supplementary after the

distance of external force.

In view of the fact that with the elastic stresses occurs residual strain, one should speak not about absolute elastic limit, but only about conditional, with some conditional amount of strain.

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During the measurement of offset yield strength, it is possible to allow considerable error, if we do not consider the time during which the specimen/sample is found under load. On the basis of the number of the investigations, carried out in Acad./Academician's laboratory. N. N. Davidenkov, this time is recommended to take as equal to 10 min [3-1].

For determining offset yield strength of the material of contact springs the amount of residual deformation $\Delta\varepsilon_{10}$ after 10 min can be accepted equal to 0.003o/o. In this case offset yield strength is designated $\sigma_{0,003}$.

More fully the material of springs characterizes curved of elastic limits, i.e., dependence curve of value $\Delta\varepsilon_{10}$

from the applied stress. The stress with which terminates the linear section of the curve of elastic limits, is called proportional elastic limit and is designated $\sigma_{пр}$.

Besides the amount of the deformation of direct/straight elastic after-effect for 10 min (Δe_{10}) for evaluating the inadequate elasticity of Acad./Academician's spring materials. N. N. Davidenkov proposed to determine also the following characteristics: the difference between the values of direct/straight elastic after-effect for 2 h and for 10 min: $m = \Delta e_{120} - \Delta e_{10}$ in o/o; the ratio of the deformation of direct/straight aftereffect for 2 h to deformation for 10 min: $k = \Delta e_{120}/\Delta e_{10}$; the value of reverse/inverse aftereffect for 1 h: $\Delta e_{обр60}$ in o/o and the reversibility of the process of aftereffect $\alpha = \Delta e_{обр60}/\Delta e_{пр120}$ in o/o.

These characteristics are named the criteria of elastic after-effect.

The contact springs of relay are manufactured largely from the nonferrous alloys (white copper, bronze so forth), which have the smaller value of the modulus of elasticity and therefore they make it possible to obtain large sagging/deflections as compared with steel springs at small

contact pressures. With the same load of spring of nonferrous alloys, have approximately two times larger sagging than the steel springs of identical size/dimensions.

However, it is necessary to note that greatest permissible amount of deflection of steel springs is approximately 1.5 times more, since they have the larger ratio of the value of allowable stress to the value of the modulus of elasticity, than spring from nonferrous alloys.

Furthermore, spring from nonferrous alloys it is considerable more easily and it is more convenient in production; they have smaller resistivity and more stable than steel in the relation to corrosion resistance.

The springs of the special types of relay must maintain/withstand prolonged operation during changes in the ambient temperature from -60 to +125°C and +200°C and increased relative humidity.

It is necessary to note that the temperature of contact springs at the work of relay is higher than the temperature of surrounding air because of the power,

scattered by winding and the contacts of relay.

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At elevated temperatures the value of offset yield strength decreases, moreover this decrease of different spring materials is different.

Springs from tin-phosphorous bronze can long work at temperature to +100°C. The value of offset yield strength of bronze at this temperature is equal to approximately $\sigma_{0,003}$ = 30 kg/mm². At temperature above 100°C elastic limit of the phosphor bronze decreases.

Argentan maintain/withstands long operating temperature to +200°C; however for providing the constancy of the regulating parameters of spring of white copper, it is necessary to stabilize (to anneal) at the temperature higher than worker by 20°C. Offset **yield strength** of white copper at temperature of +200°C and $\Delta e_{11} = 0{,}003\%$ is equal approximately to 25 kg/mm².

Springs from the thermalization/heat-treated (refined) beryllium bronze can also long work at temperature to

150°C, if the stress in the material of springs does not exceed 35-40 kg/mm².

Spring alloys on the base of copper acquire the increased elastic properties as a result of cold plastic deformation (after rolling); therefore for the production of contact springs, they are utilized largely solid or extra-hard tape, which corresponds deformation (degree of reduction) 50-60o/o or 80-90o/o (respectively).

According to the investigations, carried out by A. G. Rakhshtadt, R. I. Mishkevich, G. S. Ionichev and L. G. Sholtomir with an increase in the degree of reduction from 50 to 80o/o modulus of elasticity of white copper (MNTs15-20) and tin- phosphorous bronze (BrOF6.5-0.15) does not virtually change, but elastic limit increases on the average approximately by 22o/o.

In the process of the cold rolling of fine/thin spring tapes, zonal stresses and the inadequacies of structure (dislocation) are distributed unevenly, and therefore is noted elastic anisotropy. The value of module/modulus and elastic limit of these alloys depends on the direction of the cut of springs (along or across the direction of

rolling), of the thickness of material and heat treatment of springs. The maximum values of module/modulus and elastic limit of white copper and tin- phosphorous bronze are reached in the springs, cut out across the direction of the rolling of tape.

The anisotropy of elastic limit is expressed more sharply than the anisotropy of the modulus of elasticity, it grow/rises with an increase in the degree of reduction and a decrease in the thickness of sheet from 0.3 to 0.2 mm.

The low-temperature incompletely recrystallized annealing of springs from argentan at 300°C during 4 h and tin-phosphorous bronze at 150°C for 1 h decreases the residual stresses after rolling and operations of machining during the production of springs, and also it leads to a change in the fine structure and are caused interphase conversions in alloys.

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As a result of the low-temperature annealing of these alloys, considerably is raised elastic limit, measured with small tolerance for residual deformation (0.002o/o), increases

relaxation resistance at the normal and elevated temperatures. Elastic limit in this case is raised by 20-46o/o, and modulus of elasticity - to 3-4o/o.

Elastic anisotropy after annealing decreases as a result of removal/taking and redistribution of residual stresses, and also the redistribution of the defects of structure.

The temperature coefficient of the modulus of elasticity has negative sign and it is equal for tin- phosphorous bronze $3.4 \cdot 10^{-4}$, for white copper $3 \cdot 10^{-4}$ and for beryllium bronze $3.8 \cdot 10^{-4}$ deg^{-1}.

Electromagnetic relays must reliably work for many years and maintain/withstand for this time without damages and disturbance/breakdowns of adjustment from 10^5 for 10^9 cycles of work (functions and release/temperings). During entire service life in equipment for the automation of relay, usually they pass from 10^5 to 10^6-10^7 cycles, at the automatic telephone exchanges of step-by-step system from 10^7 to 10^8 cycles, on ATS of coordinate system from 10^7 to 10^9 cycles and in telegraph equipment from 10^8 to 10^9 cycles.

For providing for a reliable work and stable adjustment, the contact and return springs of relay must maintain/withstand from 10^7 to 10^9 cycles without breakdowns and noticeable residual deformations with high mechanical stresses.

The contact springs of relay work long time with varying load one or of two signs; therefore the maximum allowable stress must be selected taking into account the fatigue strength of metal [3-2, 3-3, 3-4].

Endurance limit (fatigue limit) for natural steel or hardened steel at high and average/mean tempering is reached usually through 10^6-10^7 cycles and at the varying load of two signs comprises approximately 0.4 from ultimate strength (with extension). Torsional endurance limit in the analogous case is approximately equal to 0.22 from ultimate strength.

For nonferrous metals and alloys endurance limit in work over 10^7-10^8 cycles can be considered equal to 0.3-0.4 from ultimate strength, but in nonferrous alloys endurance limit does not have sharp boundary and in work over 10^8 cycles continues slowly to decrease.

The fatigue strength of the spring alloys of white copper and tin-phosphorous bronze depends cn the value of cold plastic deformation, direction of the cut of springs from tape and the heat treatment of springs.

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To Fig. 3-1, are given the curves of the dependence of the fatigue strength of white copper (MNTs15-20) and tin- phosphorous bronze (BrOF6.5-0.15) by thickness 0.2 and 0.3 mm from the number of operating cycles after deformation with the degree of reduction 50 and 80o/o for the specimen/samples, cut out along the direction of rolling of sheets.

Analogous curves for the specimen/samples, cut out across the direction of rolling of sheets, are given to Fig. 3-2. These curves are constructed according to the results of the investigations of A. G. Rakhshtadt, R. I. Mishkevich, G. S. Ionicheva and L. G. Sholtomir. Investigations were carried out during the asymmetric cycle of loading (load of one sign) and at repetition frequency of 600 cycles per minute.

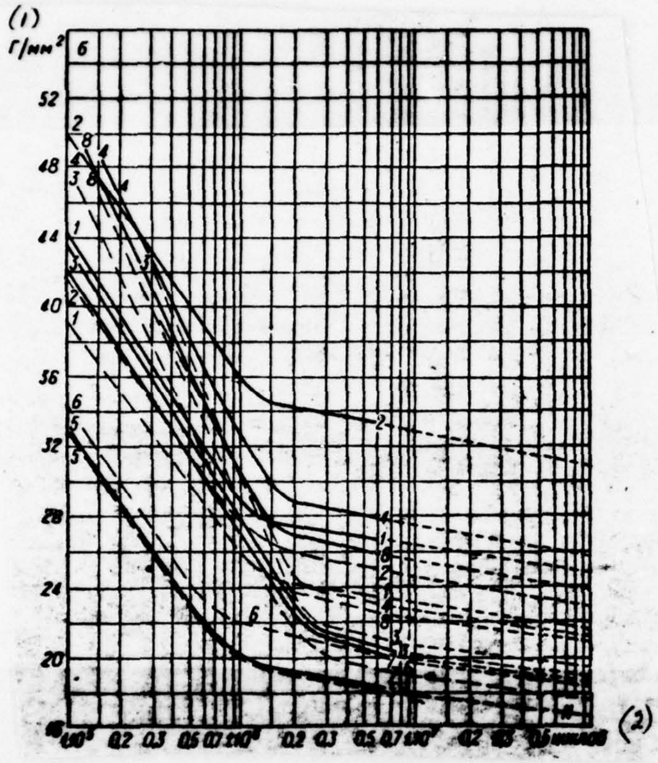

Fig. 3-1. Curved of the dependences of the fatigue strength of spring alloys on the number of operating cycles (specimen/samples are cut out along direction of rolling). 1 - BROF6.5-0.15 by thickness 0.3 mm, not annealed; 2 - the same annealed; 3 - MNTs15-20 by thickness 0.3 mm, not annealed; 4 - the same annealed; 5 - BrOF6.5-0.15 by thickness 0.2 mm, not annealed; 6 - the same annealed; 7 - MNTs15-20 by thickness 0.2 mm, not annealed; 8 - the same annealed.

Key: (1). G/mm². (2). cycles.

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With change of the endurance limit (for $5 \cdot 10^6$ cycles) of a tin-phosphorous bronze with one-sided curvature (asymmetric cycle) approximately to 10o/o and white ccpper to 4o/o. In this case, higher values endurance limits reach on the springs of larger thickness (0.3 mm) due to the more powerful effect of surface defects on the properties of fine/thin springs (0.2 mm).

The absolute value of the endurance limit of the deformed tapes is more in the specimen/samples, cut out across the direction of rolling.

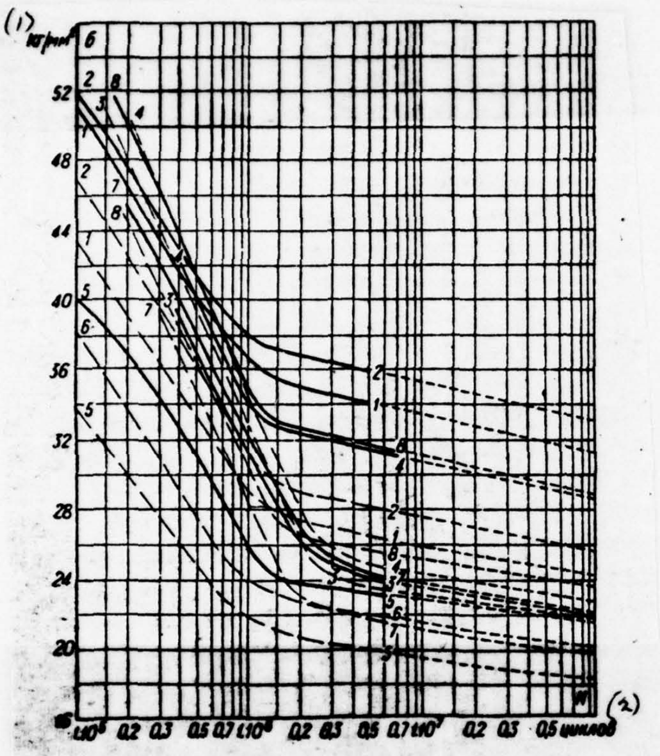

Fig. 3-2. The curves of the dependences of the fatigue strength of spring alloys on the number of operating cycles (specimen/samples are cut across direction of rolling).

Key: (1). kgf/mm². (2). cycles.

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Table 3-1. Materials for the springs of relay.

(1) МАТЕРИАЛ	(2) Марка	(3) Предел прочности при растяжении $\sigma_{пч}$, кГ/мм²	(4) Предел упругости $\sigma_{0,002}$, кГ/мм²	(5) Предел выносливости: (6) При изгибе $\sigma_{уи}$, кГ/мм²	(7) При кручении $\sigma_{ук}$, кГ/мм²	(8) Модуль упругости E, кГ/мм²	(9) Модуль сдвига G, кГ/мм²	$\sigma_{уи}/E \cdot 10^{-3}$	(10) Удельное электросопротивление ρ, ом·мм²/м	(11) Теплопроводность λ, вт/см·град	(12) Плотность γ, г/см³	(13) Химический состав, %
1	2	3	4	5	6	7	8	9	10	11	12	13
(14) Нейзильбер ленточный твердый	МНЦ 15—20	55	32–38	19	12	11 000—14 000	4 000	1,58	0,26	0,25—0,35	8,7	13,5—16,9 Ni; 18—22 Zn; примеси 0,9; ост. Cu. (15)
(16) Нейзильбер особо твердый		65	38–50	23	14,3		4 400	1,92	—	—	8,85	
(17) Фосфористая бронза ленточная твердая	БрОФ 6,5—0,15	55	29–36	19	12	9 000—11 300	4 200	1,73	0,176	0,62—0,83	8,65	(15) 6—7 Sn; 0,1—0,25 P; примеси 0,1; ост. Cu.
(18) Фосфористая бронза особо твердая		65	35–48	23	14,3		4 200	2,09	—	—	8,8	
(19) Кремне-марганцевистая бронза твердая	Бр КМЦ 3—1	65	44	23	14,3	12 000	4 200	1,92	0,15	0,33—0,45	8,4	(15) 2,75—3,5 Si; 1,0—1,5 Mn; примеси 1,1; ост. Cu.
(20) Кремне-марганцовистая особо твердая		75	50	26	16,5	12 000	4 200	2,36	—	—	—	
(21) Алюминиевая бронза ленточная термообработанная	БрА7	60	42	21	13,2	11 000—13 000	4 100	1,9	0,13	0,72—0,78	7,8	(15) 6—8 Al; примеси 1,6; ост. Cu.
(22) Алюминиевая бронза твердая		65	46	23	14,3		4 100	2,09	—	—	7,9	

Table 3-1 (continued).

(23) Бериллиевая бронза ленточная мягкая	БрБ2,5	40	25	14	9	11 700	4 800	1,2	0,10	0,84	8,22	(15) 2,3—2,6 Be; 0,2—0,5 Ni; примеси 0,5 ост. Cu.
(24) Бериллиевая бронза твердая		70	45	24	15	13 000	—	1,85	—	—	8,22	
(25) Бериллиевая бронза облагороженная		120	75	32	26	13 000	—	2,46	0,068	1,08	8,26	
(26) Латунь листовая мягкая	Л68	30	14	7	5,5	11 000	3 700	0,7	0,071	0,84—1,1	8,6	(25) 67—70 Cu; примеси 0,3; ост. Zn.
(27) Латунь листовая твердая	Л62	40	18	10	7,4	10 000	3 700	1,0	0,071	—	8,6	60,5—63,5 Cu; (15) примеси 0,5 ост. Zn.
(28) Латунь листовая особо твердая		50	23	12	9,2	—	3 700	1,2	0,071	—	8,6	
(29) Медь листовая мягкая	М3	20	2,2	7	2,8	10 800	4 200	0,65	0,019	3,9—4,1	8,8	99,5 Cu
(30) Медь листовая твердая		35	19	12	4,2	13 000	—	0,92	—	—	8,96	
(31) Сталь ленточная пружинная термообработанная:												0,6—0,7 C; 0,9—1,2 Mn; 0,17—0,37 Si; 0,04 S; 0,04 P; 0,3 Ni; 0,3 Cr.
1-й твердости (32)	У10А-1Т	130	100	46	28	20 000	8 000	2,3	0,2—0,3	0,48	7,85	
2-й твердости (32)	У10А-2Т	150	130	52	33	20 000	8 000	2,6	0,2—0,3	—	7,85	
3-й твердости (32)	У10А-3Т	170	150	60	37	20 000	8 000	3,0	0,2—0,3	—	7,85	
4-й твердости (32)	У10А-4Т	190	170	66	42	20 000	8 000	3,3	0,2—0,3	—	7,85	
(33) Сталь проволочная пружинная рояльная ($d \leqslant 0,6$ *мм*)	Р	265	—	93	58	20 000	8 000	4,65	0,19—0,22	—	7,8	—
(34) Сталь проволочная нормальной прочности	Н	170	170	59	37,4	20 000	8 000	2,95	0,19—0,22	—	7,8	
(35) Сталь проволочная повышенной прочности	П	220	—	77	48,5	20 000	8 000	3,85	0,19—0,22		7,8	
(36) Сталь проволочная высокой прочности	В	265		93	58	20 000	8 000	4,65	0,19—0,22		7,8	

Key: (1). Material. (2). Brand. (3). Ultimate tensile strength —— kg/mm². (4). Elastic limit $\sigma_{0,002}$, kg/mm². (5). Endurance limit. (6). With curvature —— kg/mm². (7). With twisting —— kg/mm². (8). Modulus of elasticity E, kg/mm². (9). Modulus of shear G, kg/mm². (10). The specific resistance ρ, $\Omega \cdot mm^2/m$. (11). Thermal conductivity λ, W/cm•deg. (12). Density γ, g/cm³. (13). The chemical

composition, o/o. (14). White copper tape/strip solid. (15). impurity/admixture —— the east. (16). White copper extra-hard. (17). The phosphor bronze tape/strip is solid. (18). The phosphor bronze extra-hard. (19). Silicon-manganese ~~Flint-marganqevista4~~ bronze ~~is~~ solid. (20). Silicon-manganese ~~Silico-ma~~nganic extra-hard. (21). Aluminum bronze tape/strip treated with heat. (22). Aluminum bronze is solid. (23). Beryllium bronze tape/strip is soft. (24). Beryllium bronze is solid. (25). Beryllium bronze refined. (26). Brass sheet is soft. (27). Brass sheet is solid. (28). Brass sheet extra-hard. (29). Copper sheet is soft. (30). Copper sheet is solid. (31). Steel tape/strip spring treated with heat. (32)/ hardness. (33). Steel wire spring is piano (d < 0.6 mm). (34). Steel wire of normal strength. (35). Steel wire of elevated strength. (36). Steel wire of high strength.

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Low-temperature annealing raises the endurance limit (for $5 \cdot 10^6$ cycles) of the solid tape of white copper and tin-phosphorous bronze approximately by 11-12o/o and extra-hard tape by 30o/o (both in longitudinal and in transverse directions). In this case, the anisotropy of

endurance limit is retained.

Endurance limit (for $5 \cdot 10^6$ cycles) for the unannealed springs from extra-hard tape, cut out across direction of rolling, is approximately to 23o/o more than in the specimen/samples, cut out along the direction of rolling of tape.

Of the annealed springs the anisotropy of endurance limit less is approximately 13o/o.

For springs of the solid tape (degree of reduction 50o/o) endurance limit (base $5 \cdot 10^6$ of cycles) of transverse specimen/samples more than in longitudinal, approximately to 11-12o/o and virtually is not changed after low-temperature annealing.

Between the endurance limits and elasticities, there is definite dependence (correlation).

Table~~s~~ 3-1 gives the physical and mechanical properties of the different metals, used for the production of the contact and return springs of relay. In this table the endurance limits are given for the heaviest case - varying

load with symmetrical cycles. For nonferrous alloys are given the endurance limits for $3\cdot10^7-5\cdot10^7$ cycles.

3-2. Flat springs.

From the theory of the bending of the elastic beam, attached by one end/lead for the greatest stress in critical section, it is possible to write the following expression:

$$k_b = \frac{M}{W_z} = \frac{Fl}{W_z}, \qquad (3\text{-}1)$$

where M is the bending moment in this section;

W_z — the moment of resistance of the cross section of spring of relatively neutral z axis;

F - load;

l — the length of spring.

Moment of resistance for the rectangular cross section

$$W_z = \frac{bh^2}{6}. \qquad (3\text{-}2)$$

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From equation (3-1) we find expression for the carrying capacity of flat spring:

$$F_m = \frac{k_b W_z}{l} = \frac{bh^2}{6} \cdot \frac{k_b}{l}, \qquad (3\text{-}3)$$

whence for the thickness of spring we obtain the following formula:

$$h = \sqrt{\frac{6Fl}{bk_b}} \qquad (3\text{-}4)$$

or

$$h\sqrt{b} = \sqrt{\frac{6F_m l}{k_b}}. \qquad (3\text{-}4a)$$

The value of allowable stress k_b for extra-hard white copper or the phosphor bronze let us accept equal to 2300 kgf/cm²; then

$$h\sqrt{b} = 0{,}0511\sqrt{F_m l}. \qquad (3\text{-}4b)$$

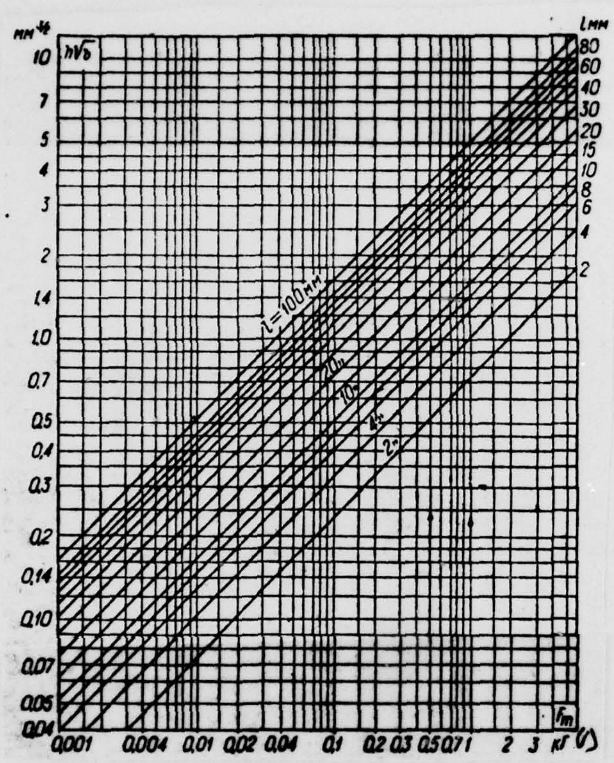

Fig. 3-3. Curved of the dependences of product $h\sqrt{b}$ on full load at the different length of springs (MNTs 15-20; BrOF6.5-0.15).

Key: (1)/ kgf.

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To Fig. 3-3, are given dependence curves of product $h\sqrt{b}$ (h and b are expressed in mm) from the value of the **full load** of springs from extra-hard white copper or the phosphor bronze at the different length of springs, constructed with the aid of formula (3.4b).

Amount of deflection of flat spring, according to equation (2-2), is equal **to:**

$$y = \frac{Fl^3}{3EJ}.$$

Substituting in this expression for F and J of their value from equations (3-3) and (2-46), we find formula for the greatest **permissible sagging/deflection of flat** spring:

$$y_m = \frac{2l^2k_b}{3hE}. \qquad (3\text{-}5)$$

If are assigned length and the greatest spring sag, then from equation (3-5) it is possible to obtain formula for determination of **the smallest thickness of the** spring:

$$h = \frac{2}{3}\cdot\frac{l^2k_b}{Ey_m}. \qquad (3\text{-}6)$$

The width of spring, if is known its thickness, can be found from equation (3-4):

$$b = \frac{6Fl}{h^2k_b}. \qquad (3\text{-}7)$$

The rigidity of flat spring, according to equation (2-2), is equal to:

$$a = \frac{F}{y} = \frac{3EJ}{l^3} = \frac{Ebh^3}{4l^3}, \qquad (3\text{-}8)$$

whence

$$\frac{a}{b} = \frac{Eh^3}{4l^3}.$$

Let us substitute into this expression for h its value from formula (3-6); we will obtain:

$$\frac{a}{b} = \frac{E}{4l^3}\left(\frac{2}{3}\,\frac{l^2k_b}{Ey_m}\right)^3 = 0{,}074\,\frac{l^3k_b^3}{E^2y_m^3}. \qquad (3\text{-}9)$$

For flat springs from extra-hard phosphor bronze ($k_b = 23$ kg/mm^2 and E = 11000 kgf/mm^2) the ratio of rigidity to the width of spring will be equal to:

$$\frac{a}{b} = \frac{F}{by} = 0{,}744\cdot10^{-5}\,\frac{l^3}{y_m^3}. \qquad (3\text{-}9a)$$

If load is expressed in grams and the size/dimensions of springs in millimeters, then

$$\frac{a}{b} = 7{,}44\cdot10^{-3}\,\frac{l^3}{y_m^3}. \qquad (3\text{-}9b)$$

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To Fig. 3-4, are given the curves of the dependences of the ratio of rigidity to the width of flat springs from the phosphor bronze on the length of springs at the different values of the greatest permissible sagging/deflection of these springs, constructed with the aid of formula (3.9b).

For providing the reliable work, the great stress in the critical section of spring must be the less allowable stress with bending.

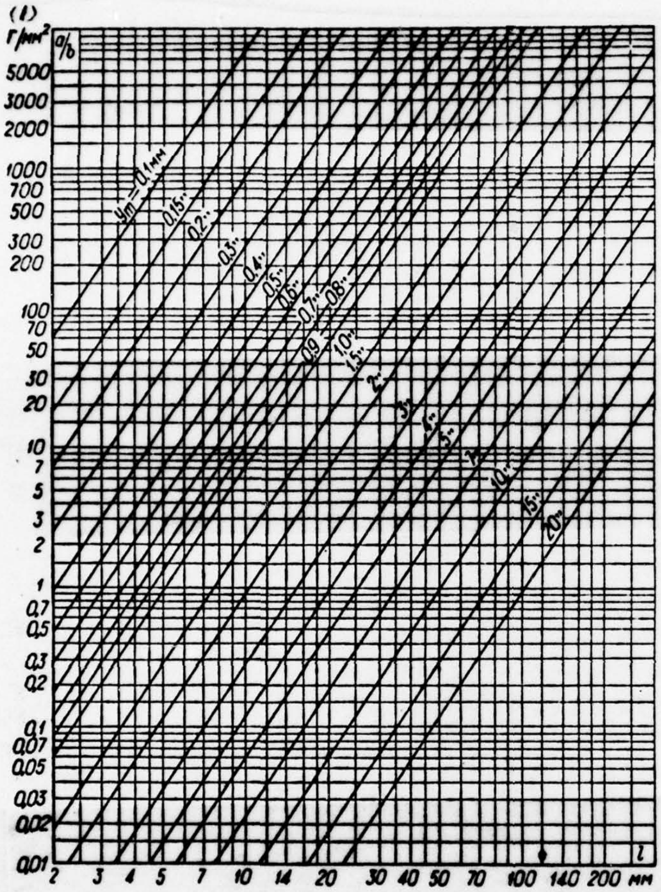

Fig. 3-4. Curved of the dependences of the ratio of rigidity to the width of flat springs on the length of springs at the different values of the greatest permissible sagging/deflection (BrOF6.5-0.15).

Key: (1). G/mm².

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The value of allowable stress depends both on the material, the construction of spring, type of load and the number of cycles which must maintain the spring during service life.

To avoid residual deformations allowable stress must not exceed elastic limit for the material of spring. for steel limit of proportionality is approximately equal to the half of ultimate strength.

The construction of spring - change in the section, grooves, opening/apertures, bendings so forth have great effect on the value of the greatest stress as a result of the concentration of stresses in the individual sections of the section of spring.

The relation of ultimate strength to allowable stress is called the safety factor (by safety factor).

With varying load with the large number of cycles, the

allowable stress must be lower than the endurance limit material approximately to 25o/o.

The value of the safety factor α for the contact springs of relay depending on their construction and type of load can vary within the range of 2 to 5.

3-3. Springs of round cross-section (wire springs).

Moment of resistance for the round cross-section

$$W_z = \frac{\pi d^3}{32} \approx 0,1d^3, \qquad (3\text{-}10)$$

where d is a diameter of the section of spring.

The carrying capacity of wire spring with the bending

$$F_{m.} = \frac{\pi d^3}{32 l} k_b, \qquad (3\text{-}11)$$

where l the length of spring.

Hence for the diameter of the wire spring, operating on bending, we obtain the following formula:

$$d = \sqrt[3]{\frac{32 F l}{\pi k_b}} = 2,16\sqrt[3]{\frac{F l}{k_b}}. \qquad (3\text{-}12)$$

Maximum spring sag of the round cross-section

$$y_m = \frac{F_m l^3}{3EJ} = 0,667 \frac{l^2 k_b}{dE}. \quad (3\text{-}13)$$

We hence find expression for determining the diameter of the spring of round cross-section, worker to bending, if are assigned length and spring sag:

$$d = 0,667 \frac{l^2 k_b}{yE}. \quad (3\text{-}14)$$

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3-4. Helical cylindrical springs of extension.

The torsional stress in the material of the coil spring of the round cross-section

$$k_d = \frac{M}{W} = \frac{16 \cdot Fr}{\pi d^3}, \quad (3\text{-}15)$$

where M is the torsional moment,

W - moment of resistance,

r - the mean radius of the turns of spring and

d - the diameter of the wire of spring.

We hence find formula for the calculation of the diameter of the wire of the helical cylindrical spring:

$$d = \sqrt[3]{\frac{16Fr}{\pi k_d}} = \sqrt{\frac{8Fc_1}{\pi k_d}} = 1{,}6\sqrt{\frac{Fc_1}{k_d}}, \qquad (3\text{-}16)$$

where c_1 - the ratio of the mean diameter of the turns of spring D to the diameter of wire d.

In the rationally completed springs value c_1 is within the limits approximately from 5 to 10:

$$c_1 = \frac{2r}{d} = \frac{D}{d} = 5 \div 10.$$

The greatest permissible load of the helical cylindrical spring.

$$F_m = \frac{\pi d^3}{16r} k_d = \frac{\pi d^3}{8D} k_d. \qquad (3\text{-}17)$$

The rigidity of helical cylindrical spring is the ratio of load to the appropriate elongation of the spring:

$$i = \frac{F}{y}.$$

The turn number of coil spring can be found from equation for the elongation of spring (2-62), if we substitute for F_m its value from the last/latter expression:

$$n = \frac{Gd^4}{64r^3F_m}y = \frac{Gd^4}{8iD^3} = \frac{Gd}{8ic_1^3}. \qquad (3\text{-}18)$$

to accept the length of lugs for the attachment of the helical cylindrical spring of the equal to the diameter of turns, then the length of spring approximately can be expressed by the following formula:

$$L = nd + y + 2(D + d). \qquad (3\text{-}19)$$

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3-5. Sets of contact springs.

The reliability of the operation of relay to a considerable degree depends on the stability of the set (group) of contact springs.

Contact springs in packet must be solidly attached and

not be displaced during mounting (soldering), also, under operating conditions during the fluctuations of temperature and humidity, since during the displacement of springs their follow of relay springs and pressure intc contacts strongly change.

Therefore insulation spacers between springs are manufactured from the durable and nonhygrcscopic materials, unshrinkableta at considerable pressures, the fluctuations of temperature and humidity.

The separators of relay usually are made out of high-quality getinax (brand $Б_в$). In the special types of relays often are applied the separators of plastic or fiberglass laminate.

For the relay, working with high humidity, must be applied the separators, passed vacuum bakelization.

Before the assembly of separator, it is necessary to maintain/withstand for a day at temperature of 65°C. The sets of springs must be collect/built with dry separators and braced under large pressure (600-1400 kgf) for providing the stability of adjustment for a long time during changes

in the temperature and humidity [18-7].

Separators must have sufficiently large contact surface so that the specific pressure would not exceed elastic limit of material.

The screw/propellers, which brace contact packets, must be made of high-grade steel with permissible tensile stress not less than 70 kg/mm².

Tension of screw/propellers is selected in such a way that the springs with assembly reliably would be held in packet, and during the fluctuations of temperature and humidity, the stress in the material of screw/propeller outside exceeded elastic limit. The value of tension of screw/propellers at the assembly of packets must accurately be monitored.

Electromagnetic relays usually undergo alternations in the humidity, since in the heated locations by summer humidity is higher than in winter. Experimentally establish/installed that 6 days of the stay of relay at relative humidity 90o/o and temperature 30°C and 6 days of the stay with of temperatures 60°C are equivalent to the

determination of relay in the heated location during one year.

Carrying out the measurements of the parameters of relay after several such cycles, it is possible to obtain the representation of the stability of the set of contact springs.

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In the new pressurized/sealed types of relay, package type contact systems are not applied. For providing the high stability of the regulating parameters during the large fluctuations of the temperature of surrounding air (from -60 to +200°C) the contact system of relay is comprised from the separate springs, soldered directly to the internal end/leads of the metallic leading-out pins. These pins are assembled on the rigid metallic foundation (base) of relay and are insulated from foundation by glass insulating beads.

3-6. Examples.

a) let us determine the thickness of the springs of contact group to breaking r of relay of the type RPN. Material of springs extra-hard white copper of brand MNTs15-20.

On the basis of endurance limit, it is selected allowable stress on bending $k_b' = 15$ kg/mm², safety factor is equal to 4.33.

The force F_c, applied to the upper spring of group, in running order is equal to 36 g, the distance of the point of application of force from the bearing edge of spring $l_c = 61$ mm, the width of spring b = 3.5 mm.

The thickness of spring we find from equation (3-4):

$$h = \sqrt{\frac{6Fl}{bk_b}} = \sqrt{\frac{6 \cdot 0{,}036 \cdot 61}{3{,}5 \cdot 15}} = 0{,}5 \text{ мм}.$$

The greatest permissible sagging/deflection for this spring will be:

$$y_m = \frac{2}{3} \cdot \frac{l^2}{h} \cdot \frac{k_b}{E} = \frac{2 \cdot 61^2 \cdot 15}{3 \cdot 0{,}5 \cdot 12 \cdot 10^3} = 6{,}23 \text{ мм}.$$

b) Let us determine the diameter of the wire of recurrent coil spring of the armature of relay. Material of wire - steel carbonic of the normal strength of brand NK.

On the basis of endurance limit, we take permissible stress on torsion $k_d = 23$ kg/mm². The safety factor is equal to 7.4. Module/modulus of elasticity with displacement G = 8000 kg/mm². ¶ Initial tension of spring is equal to 132 g, final 140 g.

The elongation of spring during the function of relay (during armature travel) is equal to 0.32 mm.

The ratio of the mean diameter of the turns of spring to the wire diameter we take equal to 10 (c_1 = 10).

Spring constant

$$i = \frac{F_1 - F_0}{y} = \frac{0{,}140 - 0{,}132}{0{,}32} = \frac{0{,}008}{0{,}32} = 0{,}025 \text{ kgf/mm.}$$

The diameter of the wire of helical cylindrical spring we find from equation (3-16):

$$d = 1{,}6 \sqrt{\frac{F_1 c_1}{k_d}} = 1{,}6 \sqrt{\frac{0{,}14 \cdot 10}{23}} = 1{,}6 \sqrt{0{,}061} \approx 0{,}4 \text{ мм}$$

The mean diameter of the turns of the spring

$$D = 10 \cdot 0{,}4 = 4 \text{ мм}.$$

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The turn number of helical cylindrical spring must be equally

$$n = \frac{Gd}{8ic^3} = \frac{8000 \cdot 0{,}4}{8 \cdot 0{,}025 \cdot 10^3} = 16.$$

Extension of spring with the greatest load

$$y_m = \frac{F_1}{i} = \frac{0{,}14}{0{,}025} = 5{,}6 \text{ мм}.$$

Length of spring in running order, according to formula (3-17),

$$L = nd + y_m + 2(D + d) = 16 \cdot 0{,}4 + 5{,}6 + 2(4 + 0{,}4) = 20{,}8 \text{ мм}.$$

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Chapter Four.

CALCULATION OF MAGNETIC CIRCUIT.

4-1. Characteristics of magnetic materials.

The magnetic materials, used for the production of relay, can be divided into two basic groups: a) magnetically soft, that possess small coercive force and high magnetic permeability at the average values of magnetic intensity (approximately from 2 to 100 A/cm), and b) magnetically hard, which possess large coercive force and considerable magnetic energy.

a) Magnetically soft materials.

To the magnetically soft materials are related

low-carbon transformer steel of brands E, EA, EAA, the qualitative structural carbon steel of brands 05, 08, 10 and 15, silicide alloy steels of brands E1, E2, E3, E4, E46 and E330, nickel alloys with high permeability in weak fields - Permalloy and cobalt alloys with high magnetic saturation - Permendur.

For the production of the magnetic circuits of electromagnetic relays, usually are applied low-carbon transformer steels of brands EA and E, that are characterized by the very low content of the undesirable impurity/admixtures: carbon, sulfurs, phosphorus, oxygen and nitrogen (C $\leqslant$ 0.04o/o; S $\leqslant$ 0.03o/o; P $\leqslant$ 0.025o/o; O_2 $\leqslant$ 0.05o/o and of N_2 $\leqslant$ 0.0035o/o).

The coercive force of steels of these two brands (in the annealed state) is within the limits from 0.5 to 1.0 A/cm, and maximum magnetic permeability (relative) oscillates within limits from 3500 to 5500.

In certain cases for magnetic circuit electromagnetic relay, are applied the qualitative structural carbon steel of brands 05, 08 and 10, which have coercive force from 0.7 to 1.7 A/cm and maximum permeability 2000-4000.

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Pages 118 and 119.

Table 4-1. Magnetic-soft materials.

(1) Наименование материала	(2) Марка	(3) Задерживающая (коэрцитивная сила) H_c, а/см	(4) Остаточная индукция B_r, тл	(5) Индукция насыщения B_s, тл	(6) Начальная проницаемость μ_a относительная	(7) Максимальная проницаемость относительная $\mu_m \times 10^3$	(8) Индукция при μ_m B, тл	(9) Потери на гистерезис при насыщении, мдж/см³·цикл	(10) Удельное сопротивление ρ·10⁻⁸, ом·м	(11) Плотность γ, г/см³	(12) Химический состав в %: C	Si	Mn	S	P
												(13) не более			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(14) **Низкоуглеродистые стали**															
(15) Карбонильное железо	—	0,08–0,24	0,5–0,6	2.17	2 000	20	—	—	9.6	7.87	0.0006	—	—	—	—
(16) Электролитическое железо, плавленое в вакууме, отожженное	—	0,24–0,32	1.0–1.3	2.16	500–700	13–15	0,7	0.1	9.8	7.88	0.012	0,004	0,008	0,001	0,008
(17) Шведская сталь древесноугольная отожженная	—	0,32–0,64	1,0–1,3	2.16	250	5–7	0,75	0,22–0,35	10.5	7,85	0,027	0,006	0,03	0,002	0,008
(18) Сталь низкоуглеродистая электротехническая тонколистовая отожженная	Э	0,64–0,95	1.0–1.4	2.14	200	3,5–5,0	0,9	0,22–0,40	10–11	7,85	0,04	0,20	0,20	0,03	0,025
(19) То же	ЭА	0.48–0.80	1.0–1.3	2.14	—	4.5–5.5	0,9	—	10–11	7.85	0,04	0.20	0.20	0.03	0.025
»	ЭАА	0,32–0,64	—	2.15	—	4,5–6,0	0,9	—	10–11	7,85	0,04	0.20	0.20	0.03	0.025
(20) Прутки из электротехнической стали горячекатаные	А и Э	0,56–1,00	1.0–1.2	2,14	—	3–5	—	—	10–14	7,85	0,035	А 0.035 Э 0.30	0.035 0.20	0.025	0.015
(21) Сталь качественная конструкционная отожженная	05	0,64–1.2	0,9–1,2	2,13	—	3–4	0,85	—	11–12	7,85	0,05	0.03	0.20	0,03	0,025
(C) То же	08 кп	0.80–1.36	0.9–1.3	2.13	—	2–3	0.85	0,35–0,55	11–14	7.85	0.05–0.12	0.20	0.25–0.5	0.04	0.040
»	10	0.88–1.68	—	2,13	—	2–3	—	—	11–16	7.85	0.07–0.15	0,17–0.37	0.35–0.65	0.045	0.040
(22) Сталь качественная конструкционная неотожженная	10	1,28–2.8	0,6	—	—	0,8–1,5	0,7	0,50–1,10		7.85	0,07–0,15	0,17–0,37	0,35–0.65	0.045	0.040
(23) То же отожженная	15	1,28–2,1	—	2,11	—	1,5–1,8	—	—	14–20	7,85	0,12–0,20	0,17–0,37	0,35–0,65	0.045	0,040
(24) Чугун ковкий (американский) отожженный	—	1,04–2,8	0,65	2,0	—	1,7	0,57	0,6	30–38	—	2,1–2,4	0,9–1,1	0,3	0.03	0.1
(25) Чугун серый легированный отожженный	00	3,2–4,8	0,53	1,67	180	0,62	0,32	1,2	80–120	7,3	2,5–3,5	3,0–4,0	0,6	0,03	0,3
	ЛК1	—	—	—	—	—	—	—	—	—	—	2,76–3,25	0,5–0,9	0,02–0,04	0,1–0,3
(26) Чугун серый легированный неотожженный	—	8,0–12,8	0,54	1,64	70	0,24	—	—	—	—	—	—	—	—	—
(27) **Кремнистые стали**															
(28) Сталь листовая электротехническая слаболегированная	Э11	0,4–0,64	0,9–1,2	2,1	150	5–6	0,6–0,8	0,15–0,25	20–30	7,80	0,02–0,03	0,8–1,8	0,25	0,03	0,03
(29) Сталь листовая электротехническая среднелегированная	Э21	0,36–0,48	0,8–1,2	2,06	170	5–6	0,6	—	25–52	7,75	0,02–0,03	1,8–2,8	0,25	0,03	0,03
(30) Сталь листовая электротехническая повышенно-легированная	Э31	0,32–0,40	0,8–1,2	2,00	250	6–7	—	0,1–0,15	40–60	7,65	0,02–0,03	2,8–4,0	0,25	0,03	0,03
(31) Сталь листовая электротехническая высоколегированная	Э41	0,28–0,36	0,5–0,8	1,94	300–400	7,5–9	0,6–0,8	0,1–0,15	55–72	7,55	0,01	4,0–4,8	0,15	0,03	0,065
(32) Сталь листовая электротехническая высокопроницаемая	Э46	0,2	—	1,92	500	9–10	—	—	55–72	7,55	0,008	4,3–4,8	0,10	0,01	0,085
(33) Сталь листовая повышенно-легированная холоднокатаная	Э330	0,12–0,31	—	2,00	500–800	16–33	0,75	0,04–0,08	45–55	7,7	0,03	2,5–3,5	0,15	0,02	0,025
(34) Кремнистая сталь (полосовая и круглая)	—	0,24–0,48	0,5–0,8	2,00	300	—	—	0,1–0,18	52–62	7,6	0,07	3,8–4,2	0,18	0,03	0,030
(35) **Железо-никелевые сплавы**														Ni	Cr / Mo
(36) Высоконикелевый легированный пермаллой (≠ 0,2–2,5 мм)	79НМ	0,016–0,024	0,5–0,8	0,75	(20–22)·10³	120–1..	0,42	0,02	55–60	8,6	<0,03	0,3–0,5	0,8–1,1	78,5–80	— / 3,8–4,1
(37) Высоконикелевый легированный пермаллой (≠ 0,2–1 мм)	79НМА	0,008–0,016	0,3	0,75	(32–50)·10³	150–3..	0,25	0,002	56	8,86	—	—	—	—	—
(38) Высоконикелевый легированный пермаллой (≠ 0,2–2,5 мм)	80НХС	0,008–0,016	0,3–0,5	0,7	(25–35)·10³	130–17..	0,23	0,02	63	8,5	<0,03	1,1–1,5	0,6–1,1	79–81	2,6–3,0 / —
(37) Низконикелевый легированный пермаллой (≠ 0,2–1 мм)	50НХС	0,10–0,12	0,6	1,0	(2,5–3,2)·10³	20–3..	—	—	90	8,2	<0,03	1,4–1,6	0,6–1,1	49,5–51	3,8–4,2 / —
(38) Низконикелевый пермаллой (≠ 0,35–2,5 мм)	50Н	0,12–0,16	0,8	1,5	(2,3–2,8)·10³	25–3..	0,37	0,12–0,10	45–50	8,2	<0,03	0,15–0,3	0,6–1,1	45–41,5	— / —
(39) Никель (99,6% Ni; 0,15% Cu)	Н2	1,3–2,7	0,35	0,61	100–110	0,6	—	0,3	8,0	8,9	0,02	0,002	—	S 0,0003	—
(40) **Кобальтовые сплавы**														S	P
(41) Железо-кобальтовый сплав (34,5% Co; 1,5% V)		1,4	1,16	2,32	—	2,3	0,96	1,0	36	8,1	—	—	—	—	—
(42) Пермендюр (49–51% Co; 1,5–2,0% V)	К50Ф2	1,2–1,6	1,3–1,4	2,36	500–800	3,5–5..	1,10	0,8–1,2	26–30	8,2	0,08	0,15–0,30	0,15–0,30	—	—
(43) Перминвар (25% Co; 45% Ni)	42–25	0,96	—	1,55	400	2,0	—	2 500	19	—	—	—	—	—	—
(44) Перминвар (7% Co; 70% Ni)	7–70	0,48	—	1,25	850	4,0	—	—	16	8,6	—	—	—	—	—
(45) Кобальт (99,2% Co)	К1	8,0	0,49	1,8	70	0,25	0,45	0,2	9,7	8,7	0,03	0,001	0,07	0,004	0,001

Key: (1). Designation of material. (2). Brand. (3). Delaying (coercive force) ___ A/cm. (4). Remanent induction ml. (5). Saturation induction ___ of ml. (6). Initial permeability ___ is relative. (7). Maximum permeability relative ___ × 1000. (8). Induction with ___ B, ml. (9). Losses to hysteresis during saturation, mJ/cm^3/cycle. (10). Specific resistor/resistance $\rho \bullet 10^{-8}$, $\Omega \bullet m$. (11). Density γ, g/cm^3. (12). The chemical composition in o/o. (13). it is not more. (14). Low-carbon steel. (15). Carbonyl iron. (16). Electrolytic iron, melted in vacuum, annealed. (17). Swedish steel charcoal annealed. (18). Steel low-carbon electrical sheet annealed. (19). The same. (20). Bars made of transformer steel hot-rolled. (21). Steel qualitative structural annealed. (22). Steel qualitative structural not annealed. (23). The same annealed. (24). Cast iron ductile (American) annealed. (25). Cast iron gray alloyed annealed. (26). Cast iron gray alloyed not annealed. (27). Silicon steel. (28). Steel sheet electrical light-alloyed. (29). Steel sheet electrical medium-alloyed. (30). Steel sheet electrical raised-alloyed. (31). Steel sheet electrical high-alloy. (32). Steel sheet electrical high-permeable. (33). Steel the sheet raised-alloyed cold-rolled. (34). Silicon steel (is band and circular). (35). Ni-Fe alloys. (36). High-nickel alloyed Permalloy ___ mm). (37). Low-nickel

alloyed Permalloy (≠0.2-1 mm). (38). Low-nickel Permalloy (≠0.35-2.5 mm). (39). Nickel. (40). Cobalt alloys. (41). Iron-cobalt alloy. (42). Permendur. (43). Perminvar. (44). Perminvar. (45). Cobalt.

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The calculated magnetic permeability of relay usually does not exceed 500; therefore the application/use of magnetic materials with permeability is more than 3000 irrationally, since barely it affects the sensitivity of relay.

An increase in the coercive force of steel makes the stability of the parameters of relay worse, it decreases the ampere-turns of release/tempering, increases releasing time and can lead to scaling of the armature of relay with light loads.

Machining (work hardening) makes the magnetic properties of steel worse, raises its coercive force and decreases the permeability; therefore all parts of magnetic relay circuit after production must pass heat treatment (annealing) at

temperature of 800-900°C for 2-3 h with the subsequent slow cooling (decrease in temperature of approximately 60°C in hour) to 600°C.

For a decrease in the oxidation with annealing the parts must be packed in cases and poured by steel filings.

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The best results gives the annealing of parts in special containers in vacuum (5 mm Hg) at temperature of 920°C.

The annealing of steel at temperature above 950°C makes it brittle.

Low-carbon transformer steel possesses tendency toward ageing, especially if articles after annealing rapidly are cooled in air. In this case in the solution/opening of iron, can be retained surplus in comparison with solubility at 20°C quantity of carbon and nitrogen. The subsequent isolation/liberation of carbides and nitrides from α-solution in finely dispersed form causes an increase in the coercive force approximately by 50-80o/o and a decrease in the permeability by 40o/o.

For the exception/elimination of aging effect, they began necessary to produce annealing during slow cooling down to 100-300°C. then cementite, being isolated at 600-300°C, it manages to coagulate into large inclusions, it is small affecting magnetic properties.

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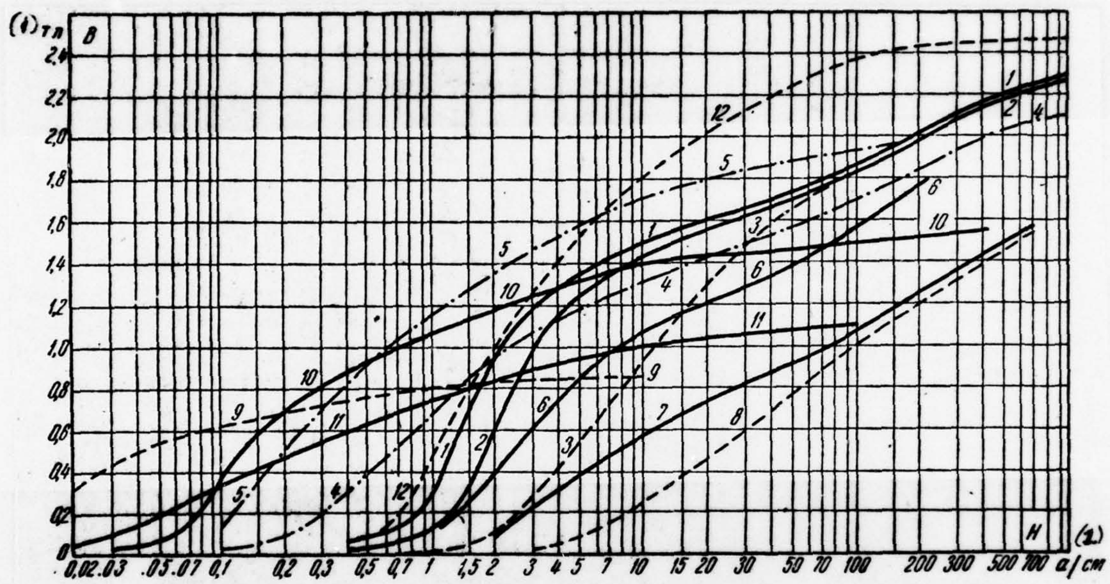

Fig. 4-1. Curve of magnetization of the magnetically soft materials. 1 - steel low-carbon is electrical, brand E, annealed; 2 - steel the qualitative structural of brand 10, annealed; 3 - steel the qualitative structural of brand 20, annealed; 4 - steel the sheet electrical of brand E4; 5 - steel electrical cold-rolled, brand E-330; 6 - cast iron ductile American, annealed; 7 - cast iron gray alloyed of brand No 00, annealed; 8 - cast iron of brand No 00, unannealed, 9 - high-nickel Permalloy (brands 79NM); 10 - low-nickel Permalloy (brands 50N); 11 - low-nickel Permalloy of brand 50 NKhS; 12. permendur.

Key: (1). Tesla. (2). A/cm.

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Artificially the ageing of steel can be reached by heating at temperature of 100°C for 600 h; however, in this case the coercive force of steel considerably increases. According to the data of the works of V. S. Mes'kin and R. I. Mishkevich the coercive force of boiling annealed steel of brand EA after stabilization for 4 h at temperature of 250-300°C does not virtually increase [4-27]. Annealing in the atmosphere of dry hydrogen decreases aging effect of steel. With annealing in hydrogen, the maximum permeability of steel increases by 50o/o, and coercive force decreases approximately two times.

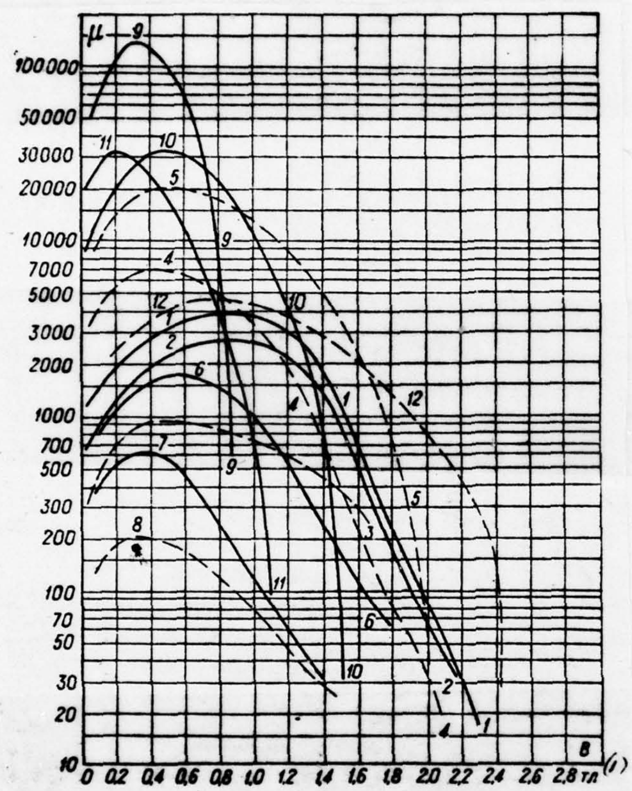

Fig. 4-2. Curves of the relative magnetic permeability of the magnetically soft materials. 1 - steel the low-carbon is electrical of brand E, annealed; 2 - steel the qualitative structural of brand 10, annealed; 3 - steel the qualitative structural of brand 20, annealed; 4 - steel the sheet electrical of brand E4; 5 - steel electrical cold-rolled of brand E330; 6 - cast iron ductile American, annealed; 7 - cast iron gray alloyed of brand No 00, annealed; 8 - cast iron of brand No 00, not annealed; 9

- high-nickel Permalloy (brands 79NM); 10 - low-nickel Permalloy (brands 50N); 11 - low-nickel Permalloy, brands 50 NKhS; 12. permendur.

Key: (1). Tesla.

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The subsequent ageing of steel (annealed in hydrogen) is led to an increase in the coercive force in all by 15-20o/o and small decrease in the permeability.

The additive of silicon decreases the effect of the ageing of steel, with the content of silicon of approximately 4o/o, ageing practical is absent.

The magnetic and electrical characteristics of magnetically soft materials are given in table 4.1.

To Figs. 4-1 and 4-2, are given curve magnetization also of magnetic permeability for different magnetically soft materials, constructed by author.

With an increase in the temperature, the saturization magnetization of ferromagnetic materials continuously decreases and reaches to zero at the specific temperature, called Curie point.

For iron the Curie point is equal to 770°C, for silicon steel 690-740°C, for Permalloy (50o/o) 500°C, for Permalloy (79o/o) 550°C and for permendur 980°C.

To Fig. 4-3, are given the curves of the dependences of magnetic induction in iron on the temperature at the different values of the strength of magnetizing field.

With the strength of magnetizing field of approximately 1.6 A/cm, the induction in iron first grow/rises with an increase in the temperature, it reaches maximum at temperature of 300-600°C and further sharply descends to zero at θ = 770°C. With the strength of field of approximately 16 A/cm, the induction is virtually constant in the range of temperatures from -200 to +500°C, while with the large strengths of field (800 A/cm) induction continuously decreases with an increase in the temperature.

Coercive force and remanent induction of iron with

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)
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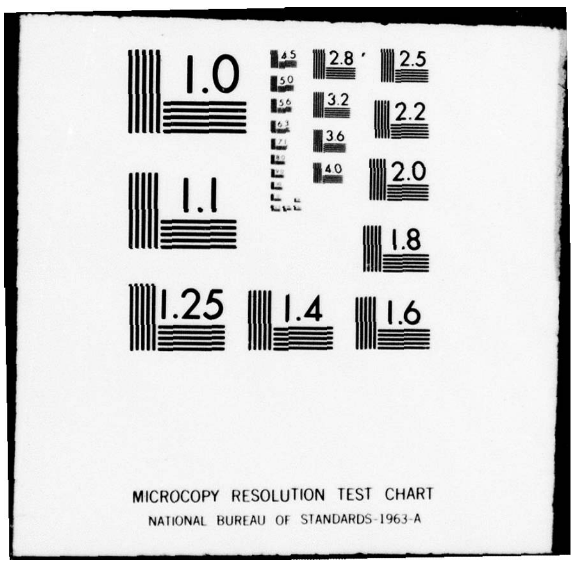
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

increase of temperature decrease. With an increase in the temperature from 20 to 400°C, the coercive force of iron decreases approximately two times.

The magnetic circuits of the relay of alternating current often are manufactured from sheet tranformer steel with the thickness 0.35-0.50 mm, which is characterized by low eddy current losses and hysteresis.

The eddy currents, which appear in magnetic circuit, gear down of function and release/tempering of relay.

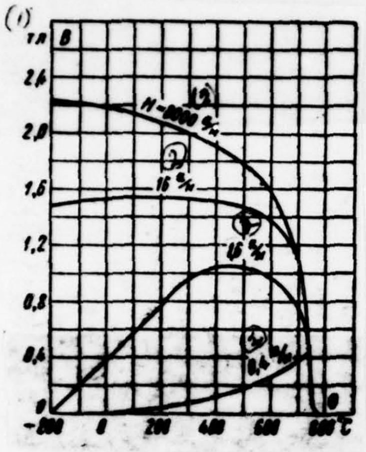

Fig. 4-3. Curved of the dependences of magnetic induction in iron on the temperature at the different values of magnetic intensity.

Key: (1). Tesla. (2). A/m.

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For a decrease in the retarding action of eddy currents, the cores of high-speed relays are manufactured from silicon steel (3-4o/o of Si) or nickel alloy (45-50o/o of NI), which have large saturation induction and high resistivity. For the magnetic circuits of the highly sensitive electromagnetic and polar relays, is applied the

alloyed Permalloy of the brand 79NM, which possesses very small coercive force, low saturation induction and high specific resistor/resistance.

For the cores, battery supply relays, is applied silicon steel or tubes (plate) from sheet tranformer steel or Permalloy, arrange/located on the surface of core made of low-carbon steel.

Parts of Permalloy after machining must be also annealed in vacuum or hydrogen at temperature of 1100-1200°C for 3 h with slow cooling (100°C in hour) to 650°C and with the subsequent rapid cooling (100°C from s) down to temperature below 300°C.

The permeability of magnetic materials in weak fields to 0.1-0.2 A/cm can be approximately calculated according to the following formula:

$$\mu = \mu_a (1 + 1{,}25 \cdot \beta H), \qquad (4\text{-}1)$$

where μ_a — initial permeability; H - field in A/cm and β - is constant for this material (table 4-2).

Hysteresis losses depend on the value of magnetic

induction and frequency and can be determined in the following formula:

$$P_r = \eta f B_m^{1,6} V, \qquad (4\text{-}2)$$

where η — the loss factor, B_m — the amplitude of magnetic induction and v - space of magnetic circuit. Value η for steel of brands E and EA is equal approximately to 0.001.

For practical calculations of hysteresis losses, usually is applied the formula:

$$P_r = \sigma_r \frac{f}{100} B_m^{1,6} V \gamma \cdot 10^{-3}, \qquad (4\text{-}2a)$$

where γ - specific gravity/weight and σ_r — the coefficient whose value is given in table 4-2. For inductions above 1 mℓ of hysteresis loss are proportional B^2.

Eddy current losses for sheet steel with the sinusoidal form of the curve of flow are equal to:

$$P_в = \frac{4}{3\rho_m} k_ф^2 f^2 B_m^2 \Delta^2 V, \qquad (4\text{-}3)$$

where $k_ф$ — the factor of the form of the curve of flow; ρ_m — the resistivity of steel and Δ - thickness of sheet.

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Table 4-2. Steel electrical sheet.

(1) Наименование материала	(2) Марка	(3) Толщина листа, мм	(4) Магнитная индукция, тл				(6) Удельные потери, вт/кг, при f = 50 гц		(8) Коэффициент потерь		(9) Постоянная
			B_{25}	B_{50}	B_{100}	B_{300}	$P_{1,0}$	$P_{1,5}$	$\sigma_г$	$\sigma_в$	в
			не менее (5)				не более (7)				
(10) Горячекатаная сталь		2,0	—	—	—	—	23,4	78	4,4	89,6	7.7
		1,5	—	—	—	—	14,5	59	4,4	50,5	
(11) Слаболегированная	Э11	1,0	1,53	1,63	1,76	2,00	5,8	13,4	4,4	14,4	
	Э11	0,5	1,53	1,64	1,76	2,00	3,3	7,7	4,2	4,8	
	Э12	1,0	1,50	1,62	1,75	1,98	5,5	12,5	—	—	
	Э12	0,5	1,50	1,62	1,75	1,98	3,2	7,5	3,6	4,2	
(12) Среднелегированная	Э13	0,5	1,50	1,62	1,75	1,98	2,8	6,5	3,6	2,8	12.[illegible]
	Э21	0,5	1,48	1,59	1,73	1,95	2,5	6,1			
(13) Повышеннолегированная	Э31	0,50	1,46	1,57	1,72	1,94	2,0	4,4	2,85	2,30	19,0
	Э31	0,35	1,46	1,57	1,71	1,92	1,6	3,6	2,60	1,15	
(14) Высоколегированная (трансформаторная)	Э41	0,50	1,46	1,57	1,70	1,90	1,55	3,5	2,6	1,2	38.4
	Э41	0,35	1,46	1,57	1,70	1,90	1,35	3,0	2,3	0,6	
	Э42	0,50	1,45	1,56	1,69	1,89	1,4	3,1	2,4	0,8	
	Э42	0,35	1,45	1,56	1,69	1,89	1,2	2,8	2,15	0,5	
	Э43	0,50	1,44	1,55	1,69	1,89	1,25	2,9	2,2	0,6	
	Э43	0,35	1,44	1,55	1,69	1,89	1,05	2,5	1,9	0,4	
(15) Холоднокатаная текстурованная повышеннолегированная	Э310	0,50	1,75	1,83	1,91	1,98	1,1	2,45	3,2	—	38,4
	Э320	0,50	1,80	1,87	1,92	2,00	0,9	2,1	2,8	—	
	Э330	0,50	1,85	1,90	1,95	2,00	0,8	4,75	2,5	—	
	Э310	0,35	1,75	1,83	1,91	1,98	0,8	1,75	2,5	—	
	Э320	0,35	1,80	1,87	1,92	2,00	0,7	1,5	2,2	—	
	Э330	0,35	1,85	1,90	1,95	2,00	0,6	1,3	1,9	—	
	Э330А	0,35	1,85	1,90	1,95	2,00	0,5	1,1	1,6	—	
						(16) при f = 400 гц					
(17) Горячекатаная высоколегированная			B_5	B_{10}	B_{25}	$P_{0,75}$	$P_{1,0}$				
	Э44	0,35	1,21	1,30	1,44	10,7	19,0				
	Э44	0,2	1,20	1,29	1,42	7,2	12,5				
	Э44	0,1	1,19	1,28	1,40	6,0	10,5				
(18) Холоднокатаная текстурованная высоколегированная	Э440	0,2	1,50	1,60	1,70	7,0	12,0				

Key: (1). Designation cf material. (2). Brand. (3). Thickness of sheet, mm. (4). Magnetic induction, mT. (5). it is not less. (6). Specific losses, W/kg, with f = 50 Hz. (7). it is not more. (8). Loss factor. (9). Constant. (10). Hot-rolled steel. (11). Slightly alloyed. (12). Medium-alloyed. (13). Raised-alloyed. (14). High-alloyed (transformer). (15). Cold-rolled textured raised-alloyed. (16). With. (17). Hot-rolled high-alloy. (18). Ccld-rolled grain-oriented high-alloy.

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In practice eddy current losses during a sinusoidal change in the flow are conveniently determined from the formula:

$$P_{в} = \sigma_{в}\left(\frac{f}{100}B_m\right)^2 V\gamma \cdot 10^{-3}. \qquad (4\text{-}3a)$$

The value of coefficient $\sigma_{в}$ is given in table 4-2.

During the computaticn of eddy current losses in thick sheets, it is necessary to consider the effect of the displacement of flow by eddy currents. For this, eddy current loss it is necessary to multiply by coefficient $k'_{в}$.

value of which can be found from formula [8-1]:

$$k_{n}' = \frac{3}{p_1} \cdot \frac{\operatorname{sh} p_1 - \sin p_1}{\operatorname{ch} p_1 - \cos p_1}, \qquad (4\text{-}4)$$
$$p_1 = \Delta \sqrt{\frac{\omega\mu\mu_0}{2\rho_m}}.$$

If value p_1 is more than three (p_1 > 3), then coefficient k_{n}' number system by sufficient accuracy it is possible to calculate according to the approximation formula:

$$k_{n}' \approx \frac{3}{p_1}. \qquad (4\text{-}4a)$$

b) Magnetically hard materials.

To magnetically hard materials are related quenched on martensite (ductile) magnet steels being deformed - carbon, chromium, tungsten and cobalt steels: inductile α-alloy - Alni(YuN), Alnis(YuNK), Alnico and Magnico (anko 4) and ductile α- and γ- alloys - vicalloy, iron-nickel-copper and cobalt-nickel-copper.

Magnetically hard materials possess large coercive force from 50 to 650 A/cm and it is above; they are applied for the production of the permanent magnets in the polar relays, the bells and other electromagnetic mechanisms.

For a polar relay and bells, are applied the largely deformed (ductile) chromium steel of the brand EKh3 and inductile aluminum-nickel alloy of brand ANZ.

Magnets made of chromium steel after production must pass heat treatment - heating to 850°C during 10-15 min and the oil quenching.

Aluminum-nickel steel possesses very large hardness and brittleness and does not yield to machining; therefore magnets from this steel are usually manufactured with casting with following polishing of working surfaces.

Recently for the production of the magnets of small size/dimensions made of aluminum-nickel steel, begin to be applied the methods of ceramic metal (pressing from powder and sintering at temperature of approximately 1300°C).

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Table 4-3. Magnetically hard materials for the permanent magnets.

(1) Наименование материала	(2) Марка	(3) Задерживающая (коэрцитивная сила) H_c, а/см	(4) Остаточная индукция B_r, тл	(5) Максимальная внешняя энергия $\left(\frac{B_d H_d}{2}\right)_{макс}$ дж/м³	(6) Оптимальное значение в воздушном зазоре (7) B_d, тл	(8) H_d, а/см	(9) Напряженность намагничивающего поля H, а/см	(10) Плотность γ, г/см³	(11) Относительный вес на единицу полезной энергии	(12) Химический состав в % C	Cr	Mn	W	Co
(13) I. Ковкие материалы														
(14) Углеродистая сталь	—	33	1,00	700	0,65	21,5	400	7,8	—	0,65	—	0,85	—	—
(15) Хромистая сталь	ЕХ	46,3	0,90	880	0,58	30,3	400	7,8	—	0,95—1,1	1,3—1,6	0,4	—	—
»	ЕХ3	47,9	0,95	960	0,62	31,2	400	7,7	17	0,9—1,1	2,8—3,6	0,4	—	—
(16) Вольфрамовая сталь	Е7В6	49,4	1,00	1 100	0,65	32,0	400	8,1	14	0,68—0,78	0,3—0,5	0,4	5,2—6,2	—
(17) Кобальтовая сталь	ЕХ5К5	70,8	0,85	1 280	0,55	46,3	800	7,7	10	0,9—1,05	5,5—6,5	0,4	—	5,5—6,5
													Mo	
»	ЕХ9К15М	135,0	0,80	2 280	0,52	87,8	800	8,3	6	0,9—1,05	8—10	0,4	1,2—1,7	
(18) II. Литые материалы										Ni	Al	Co	Cu	Ti
(19) Сплавы с нормальной магнитной энергией (20) (ални 1)	ЮН1	200	0,70	2 800	0,44	127	1 000	7,1	—	22	11	—	—	—
(ални 2)	ЮН2	342	0,60	3 800	0,37	208	1 700	—	—	24,5	13	—	3,5	—
(АН3)	ЮНД4	400	0,50	3 600	0,30	240	2 000	7,3	—	25,5	15,5	—	4,0	—
	ЮНК	600	0,40	4 300	0,24	360	3 000	—		33	13,5	—	—	—
	ЮНД8	440	0,60	5 200	0,37	280	2 200	7,6	—	28	11,0	—	8,0	0,3
	ЮНД12	500	0,52	4 400	0,29	300	2 500	7,8	—	30	11,0	—	12,0	—
(21) Сплавы с повышенной магнитной энергией (22) (алнико 12)	ЮНК1	400	0,68	5 500	0,43	255	2 000	6,9	—	18	10,0	12	6	—
(авко 2)	ЮНДК15	480	0,75	6 000	0,43	280	2 400	7,8	—	20	9	15	4	—
(24) Сплавы с высокой магнитной энергией (23) (авко 3)	ЮНДК18	550	0,90	9 700	0,57	340	2 800	7,7	—	19	10	18	3	—
(авко 4)	ЮНДК24	440	1,23	16 000	0,95	340	2 200	7,7	1,0	14	9	24	4	0,3
	ЮНДК24Т2	580	1,10	14 800	0,77	405	2 900	7,8	—	14	9	24	4	2,0
	ЮНДК35Т5	870	0,80	14 000	0,50	560	4 400	7,7	—	15	8	35	4	5,0
														Nb
	ЮНДК24Б	510	1,20	16 000	0,85	370	2 500	7,7	—	14	9	24	4	0,8
	ЮНДК25А	540	1,33	26 400	1,14	460	2 700	7,7	—	14	9	25	4	—
	ЮНДК25БА	620	1,28	26 400	1,05	500	3 100	7,8	—	15	9	25	4	0,8
(25) III. Деформируемые материалы											V			
(26) Викаллой 1	—	240	0,90	4 000	0,55	148	1 200	8,2	—	—	10	52	—	—
(26) Викаллой 2	—	360	1,00	12 000	0,82	296	1 800	7,1	—	—	14	57	—	—
											Fe			
(27) Железо-никель-медь (кунифе 1)	—	470	0,57	7 400	0,42	346	2 400	8,6	—	20	20	—	60	—
(28) Кобальт-никель-медь (кунико 1)	—	570	0,34	3 400	0,20	335	2 800	8,3	—	21	—	29	50	—
(28) Кобальт-никель-медь (кунико 2)	—	360	0,53	4 000	0,34	230	1 800	8,3	—	24		41	35	—
											Pt			
(29) Кобальт-платина	—	3 000	0,45	15 000	0,25	1 200	10 000	11,0	—	—	77	23	—	—
(30) IV. Окисные														
(31) Феррит бария изотропный	0,7БИ	1 200	0,195	2 900	0,097	600	5 000	4,4		$BaO6Fe_2O_3$	—	—	—	—
» »	1БИ	1 360	0,205	3 500	0,102	700	6 000	4,6		»	—	—	—	—
(32) Феррит бария анизотропный	2БИ	2 100	0,32	10 400	0,16	1 300	7 000	4,6		»	—	—	—	—
» »	3БИ	1 500	0,38	13 300	0,19	1 400	6 000	4,9	0,8	»	—	—	—	—

Key: (1). Designation cf material. (2). Brand. (3). Delaying (coercive force) H_c, A/cm. (4). Remanent induction B_r, by ml. (5). Maximum external energy $\left(\frac{B_d \cdot H_d}{2}\right)_{макс}$ J/m². (6). Optimum value in air gap. (7). ml. (8). A/cm. (9). Voltage magnetizing field H, A/cm. (10). Density γ, g/cm³. (11). Over-all payload ratio per unit of useful energy. (12). Chemical composition in o/o. (13). Ductile materials. (14). Carbon steel. (15). Chromium steel. (16). Tungsten steel. (17). Cobalt steel. (18). Cast materials. (19). Alloys with normal magnetic energy. (20). Alni. (21). Alloys with the increased magnetic energy. (22). Alnico. (23). Anko. (24). Alloys with high magnetic energy. (25). The materials being deformed. (26). Vicalloy. (27). iron-nickel-copper (cunife). (28). cobalt-nickel-copper (cunico). (29). cobalt-platinum. (30). Oxide. (31). Ferrite of barium is isotropic. (32). Ferrite of barium is anisotropic.

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Barium ferrites have considerably greater coercive force than magnets from aluminum-nickel alloys, but the temperature coefficient of barium ferrites is relatively great.

Remanent induction of barium ferrites during a temperature decrease within limits from +150 to $-65^{o}C$ decreases by 0.2o/o by each ^{o}C.

A deficiency/lack of barium magnets is also their low mechanical strength (brittleness).

The magnetic characteristics of the magnetically hard materials are given in Fig. 4-4 and in table 4-3.

4-2. Fundamental equations of magnetic relay circuit.

Magnetic flux along the length of the magnetic circuit of relay changes as a result of the presence of the leakage fluxes (escape), which are closed through airspace, which surrounds core and body.

The value of the magnetic flux, passing through the clearance of relay (useful flow), as a result of the presence of leakage fluxes is considerably lower than the flow in base (framework).

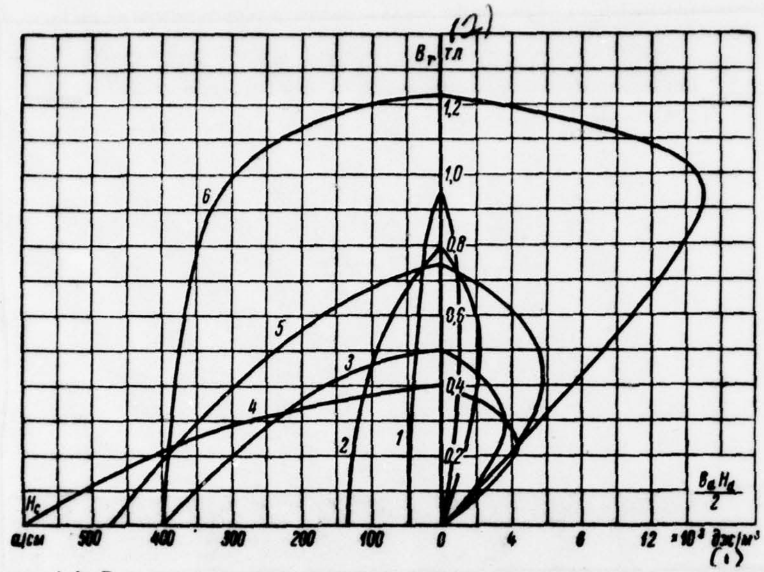

Fig. 4-4. Demagnitizing curved and curves of magnetic energy of magnetically hard materials. 1 - chromium steel of the brand EKh3; 2 - cobalt steel of the brand YeKh3K15M; 3 - alloy of brand YuND4 (AN3); 4 - alloy of the brand YuNK (ANK); 5 - alloy of the brand YuNDK15 (Anko 2); 6 - alloy of the brand YuNDK24 (Anko 4).

Key: (1). J/m³. (2) T.

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Let us find the law of magnetic flux distribution along the length of the magnetic circuit of relay, depicted in Fig. 4-5a.

Let us isolate by two planes ab and a_1b_1, Perpendicular to the plane of drawing, infinitesimal cell/element of magnetic circuit with length dx at a distance of x from base. Let us designate the flow, passing through plane ab, through Φ_x; then through plane a_1b_1 it will pass the flow

$$\Phi_x + \frac{\partial \Phi_x}{\partial x} dx.$$

Consequently, leakage flow from cell/element dx is equal to:

$$d\Phi_x = \Phi_x - \left(\Phi_x + \frac{\partial \Phi_x}{\partial x} dx\right) = -\frac{\partial \Phi_x}{\partial x} dx.$$

On the other hand,

$$d\Phi_x = U_{mx} g dx$$

or

$$\frac{\partial \Phi_x}{\partial x} = -U_{mx} g, \qquad (4\text{-}5)$$

where g is permeance of leakage fluxes per the unit of the length (1 m) of magnetic circuit and U_{mx} — the magnetic intensity in section ab.

The magnetic intensity in plane a_1b_1 will be equal to:

$$U_{mx}+\frac{\partial U_{mx}}{\partial x}dx.$$

Increment in the magnetic intensity on cell/element dx

$$dU_{mx}=U_{mx}-\left(U_{mx}+\frac{\partial U_{mx}}{\partial x}dx\right)=-\frac{\partial U_{mx}}{\partial x}dx.$$

On the basis of second Kirchhoff's law, it is possible to write:

$$\frac{M}{l}dx-\Phi_x R_m dx+dU_{mx}=0$$

or

$$\frac{M}{l}dx-\Phi_x R_m dx-\frac{\partial U_{mx}}{\partial x}dx=0,$$

where $M=Iw-$ magnetizing force, created by winding;

R_m- the reluctance of unit of length (1 m) of magnetic circuit;

$l-$ the length of core in m.

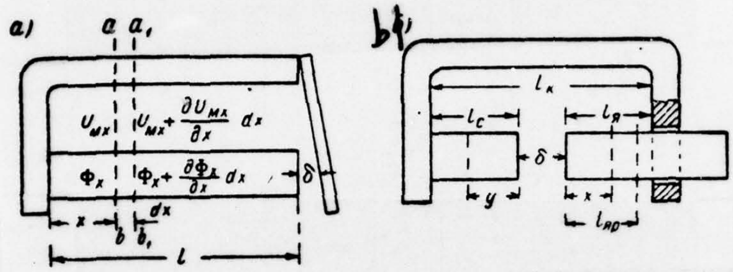

Fig. 4-5. Drawings of magnetic relay circuits: a-c by external hinged armature; b - with suction armature.

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From last/latter expression we find:

$$\frac{\partial U_{мx}}{\partial x}=\frac{M}{l}-\Phi_x R_ж. \quad (4\text{-}6)$$

Differentiating equations (4-5) and (4-6) for x and passing from partial derivatives to common/general/total, we obtain:

$$\frac{d^2\Phi_x}{dx^2}=-g\frac{dU_{мx}}{dx}$$

and

$$\frac{d^2U_{мx}}{dx^2}=-R_ж\frac{d\Phi_x}{dx}$$

Substituting for $\frac{dU_{мx}}{dx}$ and $\frac{d\Phi_x}{dx}$ their value, we find:

$$\frac{d^2\Phi_x}{dx^2} = -\Phi_{x0} g R_м + \frac{M}{l} g = 0 \qquad (4\text{-}7)$$

and

$$\frac{d^2U_{мx}}{dx^2} - U_{мx} g R_м = 0. \qquad (4\text{-}8)$$

The general solution of equation (4-8) takes the following form:

$$U_{мx} = c_1 \operatorname{sh} x\sqrt{gR_м} + c_2 \operatorname{ch} x\sqrt{gR_м}, \qquad (4\text{-}9)$$

where c_1 and c_2, integration constant,.

By differentiating the last/latter equation for x and taking into account (4-6), we find:

$$\frac{dU_{мx}}{dx} = c_1\sqrt{gR_м}\cdot \operatorname{ch} x\sqrt{gR_м} + c_2\sqrt{gR_м}\cdot \operatorname{sh} x\sqrt{gR_м} = \frac{M}{l} - \Phi_x R_м,$$

whence

$$\Phi_x = \frac{M}{lR_м} - c_1\sqrt{\frac{g}{R_м}}\cdot \operatorname{ch} x\sqrt{gR_м} - c_2\sqrt{\frac{g}{R_м}}\cdot \operatorname{sh} x\sqrt{gR_м}. \qquad (4\text{-}10)$$

If we disregard reluctance R_0 between the core and the framework (base of relay), then with x, equal to zero,

$$U_{мx} = \Phi_0 R_0 = 0.$$

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From equation (4-9) we obtain $c_2 = 0$. At the end/lead of core with x **equal to** l, **the magnetic** intensity will be:

$$U_{\text{м}l} = \Phi_l R_{\text{в}},$$

where Φ_l — **the** magnetic flux, which emerges **from the** end/lead **of the** core (useful flow), in cb **and** $R_{\text{в}}$ — the reluctance of clearance.

After substituting into equation (4-9) instead **of** $U_{\text{м}l}$ **its** value, we have:

$$\Phi_l R_{\text{в}} = c_1 \operatorname{sh} l \sqrt{g R_{\text{мк}}},$$

whence

$$c_1 = \frac{\Phi_l R_{\text{в}}}{\operatorname{sh} l \sqrt{g R_{\text{мк}}}}.$$

Substituting in equation (4-9) and (4-10) of the value of integration constants, we find:

$$U_{\text{мx}} = \Phi_l R_{\text{в}} \frac{\operatorname{sh} x \sqrt{g R_{\text{мк}}}}{\operatorname{sh} l \sqrt{g R_{\text{мк}}}} \qquad (4\text{-}11)$$

and

$$\Phi_x = \frac{M}{l R_{\text{мк}}} - \Phi_l R_{\text{в}} \sqrt{\frac{g}{R_{\text{мк}}}} \cdot \frac{\operatorname{ch} x \sqrt{g R_{\text{мк}}}}{\operatorname{sh} l \sqrt{g R_{\text{мк}}}}. \qquad (4\text{-}12)$$

Flow at end of core with x, equal to l, will be:

$$\Phi_l = \frac{M}{lR_{ж}} - \Phi_l R_{ж} \sqrt{\frac{g}{R_{ж}}} \cdot \frac{\operatorname{ch} l\sqrt{gR_{ж}}}{\operatorname{sh} l\sqrt{gR_{ж}}}$$

or

$$\Phi_l = \frac{M}{lR_{ж} + R_{в} \dfrac{l\sqrt{gR_{ж}}}{\operatorname{th} l\sqrt{gR_{ж}}}}.$$

Let us designate:

$$q = \frac{l\sqrt{gR_{ж}}}{\operatorname{th} l\sqrt{gR_{ж}}}. \tag{4-13}$$

Then formula for a flow in clearance will take the following form:

$$\Phi_l = \frac{Iw}{lR_{ж} + qR_{в}}. \tag{4-14}$$

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After substituting into equation (4-12) instead of Φ_l, its value, we obtain:

$$\Phi_x = \frac{Iw}{lR_м} - \frac{Iw}{lR_м + qR_в} \cdot \frac{R_в\sqrt{gR_м}\cdot \operatorname{ch} x\sqrt{gR_м}}{R_м \operatorname{sh} l\sqrt{gR_м}} = \frac{Iw}{lR_м + qR_в}\left(\frac{lR_м + qR_в}{lR_м} - \frac{R_в\sqrt{gR_м}\cdot \operatorname{ch} x\sqrt{gR_м}}{R_м \operatorname{sh} l\sqrt{gR_м}}\right),$$

whence we find expression for the magnetic flux of the relay:

$$\Phi_x = \Phi_l\left[1 + \frac{qR_в}{lR_м}\left(1 - \frac{\operatorname{ch} x\sqrt{gR_м}}{\operatorname{ch} l\sqrt{gR_м}}\right)\right]. \quad (4\text{-}15)$$

For practical calculations this formula can be considerably simplified. Expanding hyperbolic functions in infinite series and disregarding all terms, which have the degrees higher than second, we obtain:

$$\Phi_x = \frac{Iw}{lR_м + qR_в}\left[1 + \frac{gR_в}{2l}(l^2 - x^2)\right] = \Phi_l\left[1 + \frac{gR_в}{2l}(l^2 - x^2)\right]. \quad (4\text{-}15a)$$

where

$$q = 1 + \frac{p g R_{\text{ж}}}{3}. \qquad (4\text{-}13a)$$

Flow of heel with x, equal to zero, will be:

$$\Phi_0 = \frac{Iw}{lR_{\text{ж}} + qR_{\text{в}}}\left(1 + \frac{lg R_{\text{в}}}{2}\right) = \Phi_t\left(1 + \frac{lg R_{\text{в}}}{2}\right) \qquad (4\text{-}15b)$$

For a magnetic circuit with suction armature (solenoid type, Fig. 4-5b) the value of magnetic flux in any section along the length of movable core (plunger) can be determined by following formula [4-4]

$$\Phi_x = \Phi_t\left[1 + \frac{g l_{\text{пр}}}{G_\delta l_{\text{пр}}} \cdot \frac{x}{2}\left(2 - \frac{x}{l_{\text{пр}}}\right)\right], \qquad (4\text{-}16)$$

where $l_{\text{пр}}$ — calculated length of coil $l_{\text{пр}} = l_{\text{к}} - (l_{\text{к}} - l_{\text{пр}})$ and $l_{\text{пр}}$ — **distance from** the end/lead of **movable core to the section** in which the flow has great value.

Value

$$l_{\text{пр}} = l_{\text{к}}\left[1 - \frac{2G_\delta l_{\text{к}} - g l_{\text{к}}^2}{2l_{\text{к}}(G_\delta + G_t + g l_{\text{к}})}\right]. \qquad (4\text{-}17)$$

In this formula G_δ and G_s — permeance of worker and parasitic of air gaps.

When $x = l_{\text{кр}}$ magnetic flux in movable core (armature) reaches the maximum:

$$\Phi_m = \Phi_\delta\left(1 + \frac{g l_{\text{кр}}^2}{2G_\delta l_{\text{кр}}}\right). \quad (4\text{-}16a)$$

tab the value of the magnetic flux, passing through the parasitic gap between movable core and the passage collar

$$\Phi_l = \Phi_\delta\left[1 + \frac{g l_{\text{кр}}}{G_\delta l_{\text{кр}}} \cdot \frac{l_n}{2}\left(2 - \frac{l_n}{l_{\text{кр}}}\right)\right]. \quad (4\text{-}16b)$$

In any section, which is located at a distance of y from the end/lead of motionless core (ream/foot)

$$\Phi_y = \Phi_\delta\left[1 + \frac{g l_c}{G_\delta l_{\text{кр}}} \cdot \frac{y}{2}\left(2 - \frac{y}{l_c}\right)\right]. \quad (4\text{-}18)$$

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The approximate curve of magnetic flux distribution along the length of the core of valve type relay during R_0, equal to zero, is presented in Fig. 4-6. For tentative calculations the relationship/ratio between the useful and total flux of relay can be found from the curves of Fig. 4-7, obtained experimentally.

4.3. Effect of the reluctance of the joint of core with the base of relay.

The reluctance of the joint of core with the base of relay (housing, framework) R_0 usually not is equal to zero; in this case magnetic flux distribution along the length of core, shown in Fig. 4-5, has another character. the maximum of flow does not coincide with the origin of coordinates and it is shifted a little to the right.

Let us transfer the origin of coordinates into point b, at which the magnetic flux of relay has maximum value. Then the magnetic system of our relay can be will be considered as system, which consists of two separate, series-connected magnetic circuits ab and bc, which have ideal joint at point b with the reluctance, equal to zero. Let us designate the length of the core of the right side of the magnetic relay circuit by l_1 and the resistor/resistance of clearance R_s, respectively for the left side of the magnetic circuit l_1 and R_0.

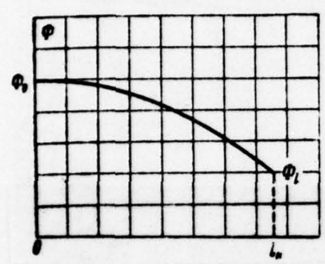

Fig. 4.6. Magnetic flux distribution along the length of core of relay, during $R_0 = 0$.

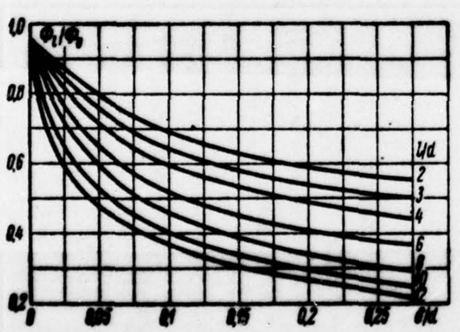

Fig. 4-7. Curved for tentative calculation of useful flow relays.

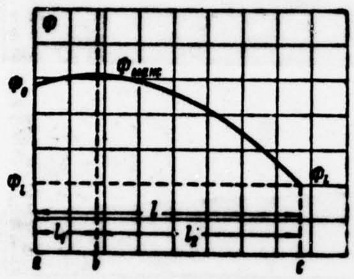

Fig. 4-8. Magnetic flux distribution along the length of core of relay during $R_0 = 0$.

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For the calculation of each of these magnetic circuits, it is possible to use the given above formulas (4-15), (4-15a) and (4-15b).

Distance l_1 from the end/lead of the core to point b let us call/name the calculated length of magnetic circuit.

If we disregard reluctance they became, then magnetic flux in the end/lead of the core it is possible to express by the following formula:

$$\Phi_l = \frac{U_{ml}}{R_m} = \frac{Hl}{R_m},$$

where H - magnetic intensity.

Let us substitute into formula (4-15a) instead of Φ_l its value

$$\Phi_x = \frac{Hl}{R_m}\left[1 + \frac{gR_m}{2l}(l^2 - x^2)\right].$$

The maximum value of magnetic fluxes (Φ'_0 and Φ''_0) in the right and left of the parts of the magnetic circuits will occur at the point of "joint" (point b):

$$\Phi'_0 = \frac{H'l_1}{R_0}\left(1 + \frac{gR_0}{2}l_1\right)$$

and

$$\Phi''_0 = \frac{H''l_2}{R_m}\left(1 + \frac{gR_m}{2}l_2\right).$$

As a result of the continuity of a change in flow and strength of field, we have:

$$\Phi'_0 = \Phi''_0 \text{ and } H' = H''.$$

Equalizing expressions for F'_0 and F''_0, we obtain:

$$\frac{l_1}{R_0}\left(1 + \frac{gR_0}{2}l_1\right) = \frac{l_2}{R_m}\left(1 + \frac{gR_m}{2}l_2\right).$$

Taking into account that $l = l_1 + l_2$, we obtain after the simple transformations of formula for determining the calculated length of the core:

$$l_2 = \frac{lR_B(R_0gl + 2)}{2(R_B + R_0 + R_BR_0gl)} \qquad (4\text{-}19)$$

and

$$l_1 = l - l_2 = \frac{lR_0(R_Bgl + 2)}{2(R_B + R_0 + R_BR_0gl)}. \qquad (4\text{-}19a)$$

In these formulas is not taken into account the effect of the reluctance of steel of magnetic circuit.

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Thus, with the aid of (4-15), (4-15a) and (4-15b) it is possible to perform the approximate computations of magnetic relay circuits also the cases when the reluctance of the joint of core with base (framework) not is equal to zero, if we instead of l substitute the calculated length of core l_2.

Examining section bc to insulation substituting in equation (4-15b) instead of l the calculated length of

core l_2 from expression (4-19), we obtain for determining the maximum value of the flow:

$$\Phi_{\text{макс}} = \Phi_l \left(1 + \frac{R_{\text{в}} g l_2}{2}\right) = \Phi_l \left[1 + \frac{R_{\text{в}}^2 g l (R_0 g l + 2)}{4(R_0 + R_{\text{в}} + R_0 R_{\text{в}} g l)}\right]. \quad (4\text{-}20)$$

From section ab, it is possible to write for the maximum flow:

$$\Phi_{\text{макс}} = \Phi_0 \left(1 + \frac{R_0 g l_1}{2}\right) = \Phi_l \left(1 + \frac{R_{\text{в}} g l_2}{2}\right). \quad (4\text{-}20a)$$

whence we obtain for a flow at heel (in the site of its joint with housing) the following expression:

$$\Phi_0 = \Phi_l \frac{R_{\text{в}} g l_2 + 2}{R_0 g l_1 + 2}. \quad (4\text{-}21)$$

Precise formulas for the calculation of magnetic circuits taking into account resistance of the joint of core with the base of relay are obtained by V. I. Kovalenkov on the base of the theory of active electrical network [4-1]:

$$\Phi_x = \frac{M}{l R_{\text{ж}}} \left\{1 - \frac{A_x [A R_0 + (c R_0 + 1) R_{\text{в}}] - c_x R_0 [B + R_{\text{в}} (A - 1)]}{B + A (R_0 + R_{\text{в}}) + c R_0 R_{\text{в}}}\right\}; \quad (4\text{-}22)$$

$$\Phi_l = \frac{M}{l R_{\text{ж}}} \left\{1 - \frac{A [A R_0 + (c R_0 + 1) R_{\text{в}}] - c R_0 [B + R_{\text{в}} (A - 1)]}{B + A (R_0 + R_{\text{в}}) + c R_0 R_{\text{в}}}\right\}; \quad (4\text{-}22a)$$

$$\Phi_0 = \frac{M}{l R_{\text{ж}}} \left[\frac{B + R_{\text{в}} (A - 1)}{B + A (R_0 - R_{\text{в}}) + c R_0 R_{\text{в}}}\right]. \quad (4\text{-}22b)$$

where

$$A_x = \mathrm{ch}\, x \sqrt{gR_ж}; \qquad c_x = \sqrt{\frac{g}{R_ж}} \cdot \mathrm{sh}\, x \sqrt{gR_ж};$$

$$A = \mathrm{ch}\, l \sqrt{gR_ж}; \qquad B = \sqrt{\frac{R_ж}{g}} \cdot \mathrm{sh}\, l \sqrt{gR_ж}$$

and

$$C = \sqrt{\frac{g}{R_ж}} \cdot \mathrm{sh}\, l \sqrt{gR_ж}.$$

These formulas for practical calculations are sufficiently complex. If we expand in them hyperbolic functions in infinite series and to disregard all terms, which have the degrees higher than second, then after the appropriate transformations we will obtain the approximation formulas for the calculation of magnetic circuits taking into account the resistor/resistance of the joint of core with the base of relay.

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Magnetic flux of the end/lead of the core (in interiron space) will be expressed as follows:

$$\Phi_l = \frac{Iw\,(R_в g l + 2)}{2\,[l(R_ж + R_0 R_в g) + q(R_в + R_0)]}. \qquad (4\text{-}23)$$

If we disregard conductivity for leakage fluxes ($g \approx 0$), then

$$\Phi_l = \frac{Iw}{lR_{ж} + R_0 + R_в}; \qquad (4\text{-}23a)$$

if we disregard reluctance they became, then

$$\Phi_l = \frac{Iw\,(R_в gl + 2)}{2(lR_0 R_в g + R_в + R_0)}. \qquad (4\text{-}23b)$$

Flow value of heel of the relay

$$\Phi_0 = \Phi_l\left[1 + \frac{(R_в - R_0)\,gl}{R_в gl + 2}\right] = \Phi_l\,\frac{R_в gl + 2}{R_в gl + 2}. \qquad (4\text{-}23c)$$

These formulas are simple and give sufficient accuracy for practical calculations.

Figures 4-9 gives experimental curved magnetic flux distributions along the length of the core of the relay of types 100 and RKN. From these curves it follows that scattering magnetic flux in relay of the type RKN due to the application/use of the pole pieces is considerably less than in relay of type 100 [1-14].

4-4. Account of the reluctance of steel.

Magnetic resistance of unit of length (1 m) of magnetic circuit $R_м$ depends on the permeability of steel and section of the sections:

$$R_м = \frac{1}{\mu_0 \mu_c S_c} + \frac{1}{\mu_0 \mu_к S_к}. \qquad (4\text{-}24)$$

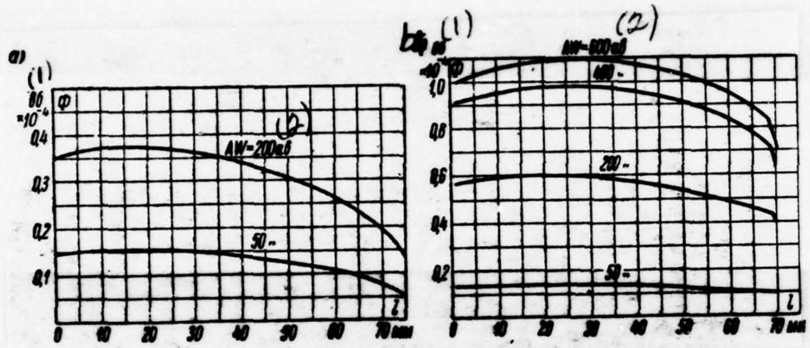

Fig. 4-9. Flow distribution along the length of core: a - relay of type 100; b) relay of type RKN.

Key: (1) Wb; (2)AV.

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Here S_c **and** S_κ — **the** sections of core and housing into $м^2$, μ_c and μ_κ — **relative magnetic** permeability of steel core **and housings and** $\mu_0 = 4\pi \cdot 10^{-7}$ **H/m** - magnetic constant.

If $S_c = S_\kappa$ **and** $\mu_c = \mu_\kappa$, **then**

$$R_{\text{мк}} = \frac{2}{\mu_0 \mu S}. \qquad (4\text{-}24a)$$

During the derivation of formulas for the calculation of magnetic circuit, value $R_{ж}$ was accepted by constant, but actually as a result of scattering of magnetic flux of induction and permeability and, consequently, also $R_{ж}$ change along the length of the core and housing of relay. Therefore by $R_{ж}$ should accept the mean reluctance of the unit of the length of magnetic circuit, and hearth μ_c and $\mu_к$ — respectively average values of magnetic permeability of steel of core and housing.

With the absence of saturation, a change in the permeability barely affects the value of useful magnetic flux in interiron space, since reluctance of interpiece of space many times is more the resistor/resistance of steel of magnetic circuit. Thus, for instance, with decrease of magnetic permeability of steel from 30,000 to 2000 useful flow in relay of type 100 (with σ = 0.9 mm) decreases in all by 5.9o/o.

Therefore during the calculation of the unsaturated magnetic circuits when induction changes approximately within limits from 0.35 to 1.3 mT, the value of average magnetic permeability it is possible to determine with the average value of magnetic flux, which is expressed by the following

formula:

$$\Phi_{cp} = \frac{1}{l}\int_0^l \Phi_x\,dx = \frac{LI}{w} \approx \frac{Iw}{R_\text{в}}\left(1 + \frac{R_\text{в}gl}{3}\right) = \Phi_l\left(1 + \frac{R_\text{в}gl}{3}\right). \quad (4\text{-}25)$$

For determining the average permeability of material during large inductions, let us divide magnetic circuit along the length into n of sections and let us designate the average magnetic permeability of each section respectively $\mu_1, \mu_2, \mu_3, \ldots, \mu_n$.

The reluctance of entire magnetic circuit of relay will be equal to the sum reluctances of the individual sections:

$$\frac{2l}{\mu_{cp}S\mu_0} = \frac{2l}{n\mu_1 S\mu_0} + \frac{2l}{n\mu_2 S\mu_0} + \ldots + \frac{2l}{n\mu_n S\mu_0}$$

or

$$\frac{1}{\mu_{cp}} = \frac{1}{n}\left(\frac{1}{\mu_1} + \frac{1}{\mu_2} + \ldots + \frac{1}{\mu_n}\right),$$

whence we obtain formula for the calculation of the tentative value of the average permeability of the magnetic circuit of the relay:

$$\mu_{cp} = \frac{n}{\frac{1}{\mu_1} + \frac{1}{\mu_2} + \ldots + \frac{1}{\mu_n}}. \quad (4\text{-}26)$$

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For determining the average permeability of individual sections, it is necessary to find induction in several sections along the length of magnetic circuit and from curve (for this brand they stopped) to determine the appropriate values of permeability $\mu_1, \mu_2, \mu_3, \ldots, \mu_n$. The accuracy of calculation, obviously, will depend on a quantity of sections. For practical calculations sufficient to determine permeability they began in three-five points.

The tentative value of average permeability during the precomputation of the relays, working during large inductions, one should select within limits approximately from 500 to 1500.

With the aid of (4-26) it is possible to check, how diverges average permeability from the accepted during calculation and by the method successive diverging of to attain a decrease in this disagreement. During the calculation of ampere-turns, the flows are assigned and average permeability is determined without translation. The reluctance of armature and base (framework) of relay can be considered, adding their value respectively to values R_a and R_0.

4-5. Determination of permeance of air sections of magnetic circuit.

Permeance of working clearance, i.e., air gap between core and armature of relay (working conductivity), and the conductivity of leakage fluxes (conductivity of leakage paths) they can be accurately calculated only in some ideal cases. In the majority of the cases for determining these conductivities, it is necessary to use the approximation and empirical formulas.

a) conductivity between two parallel planes.

If the distance between two parallel planes is small about to comparison with their size/dimensions, then the lateral scattering of lines of force can be disregarded. In this case permeance

$$G=\frac{S}{\delta}\mu_0, \qquad (4\text{-}27)$$

where S is an area of each plane in m^2 and

δ - the distance between these planes in m.

In the ratio of the section of pole S to distance δ, which exceeds 0.1, the error will not be more than 5o/o.

This formula it is possible to use for determining the conductivities of clearance with small gaps (with the pulled armature) and conductivities in joints.

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b) conductivity between the pole of core and armature.

1. Permeance between pole of round cross-section and flat/plane hinged armature (Fig. 4-10a) can be determined by formulas, obtained by N. K. Gla'tsern [4-10].

We assume that the lines of force are directed along circumference. Conductivity of the elementary tube between the pole of core and the armature, turned to angle α (in radians):

$$dG = \mu_0 \frac{y\,dx}{x\alpha} = \mu_0 \frac{2\sqrt{r^2 - (c_1 - x)^2} \cdot dx}{x\alpha},$$

where r - a radius of the pole of core,

c_1 - the distance between centers of core and the rotational axis of armature,

y - the width of elementary tube,

dx - thickness its and

x - the distance of this tube from the rotational axis of armature.

Conductivity between the pole of round cross-section and the armature

$$G = 2\mu_0 \int_{R_1}^{R_2} \frac{\sqrt{r^2 - (c_1 - x)^2} \cdot dx}{x\alpha} = \frac{2\pi}{\alpha}\mu_0 (c_1 - \sqrt{R_1 R_2}) \approx \frac{2\pi c_1}{\delta}\mu_0 (c_1 - \sqrt{R_1 R_2}), \quad (4\text{-}28)$$

where $R_1 = c_1 - r$ and $R_2 = c_1 + r$,; at small angles of rotation, can be counted $\alpha \approx \delta / c_1$.

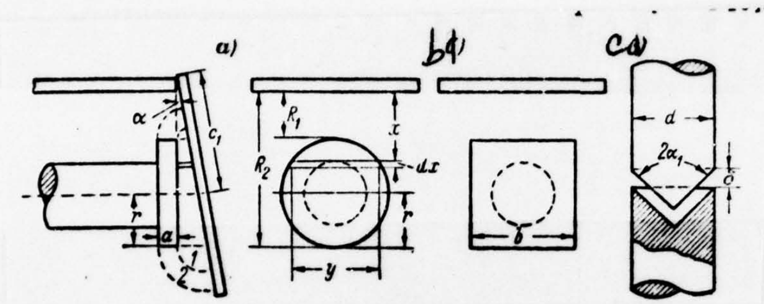

Fig. 4-10. On the calculation of conductivities: a) between pole of round cross-section and armature; b) between pole of rectangular section and armature; c) between cone-shaped surfaces.

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When value $\sqrt{R_1 R_2}$ differs little from c_1, to avoid large errors during, one should use the approximation formula:

$$G = \frac{\pi r^2 \mu_0}{\alpha c_1}\left(1 + \frac{r^2}{4c_1^2}\right) \approx \frac{\pi r^2 \mu_0}{\delta}\left(1 + \frac{r^2}{4c_1^2}\right). \qquad (4\text{-}28a)$$

Boundary magnetic fluxes enter armature in two ways: from the fin/edge, which was being formed between lateral and faces of pole G_1, and from the lateral surface of pole piece G_2.

Permeance of boundary/edge leakage paths can be determined to approximately following by the formulas:

$$G_1 = \frac{\pi^2\mu_0}{\left(\frac{\pi}{2}+1\right)^3}\left[r(\pi+2)+\frac{\pi}{2}c_1\,\mathrm{tg}\,\alpha\right] = 0{,}58\mu_0(5{,}14r+1{,}57\delta), \quad (4\text{-}29)$$

$$G_2 = 2a\mu_0\left[1+\frac{2r}{\sqrt{\left(\frac{a}{2}+R_1\,\mathrm{tg}\,\alpha\right)\left(\frac{a}{2}+R_2\,\mathrm{tg}\,\alpha\right)}}\right], \quad (4\text{-}30)$$

where a - width of the free end/lead of the core (thickness of pole piece).

At small angles of rotation $\mathrm{tg}\,\alpha \approx \delta/c_1$; expanding square root in a series and disregarding second-order quantities, we obtain:

$$G_2 = 2a\mu_0\left\{1+\frac{4r}{a+2\delta}\left[1+\frac{2r^2\delta^2}{c_1^2(a+2\delta)^2}\right]\right\} \approx 2a\mu_0\left(1+\frac{4r}{a+2\delta}\right). \quad (4\text{-}31)$$

These formulas give error not more than 5-10o/o.

General permeance of working air gap is equal to:

$$G'_\delta = G + G_1 + G_2. \quad (4\text{-}32)$$

If the armature of relay has the nonmagnetic plug (plate) of loosening, then the value of conductivity of working air gap, depending on course of armature, will be equal to:

$$G_\delta = \frac{G'_\delta G_m}{G_m - G'_\delta}, \quad (4\text{-}33)$$

where G_m — conductivity of air gap, formed between armature and core of relay with the pullled armature.

With the low value of the clearance

$$G'_\delta \approx \frac{S}{\sigma}\mu_0, \quad G_\delta \approx \frac{S}{\delta}\mu_0, \quad G_m = \frac{S}{\delta_0}\mu_0, \quad (4\text{-}34)$$

where σ is length of clearance (distance between armature and pole);

δ - the course of armature;

δ_0 - the height/altitude (thickness) of the plug of loosening.

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For determining common/general/total permeance of the working air gap of valve type, relay V. V. Vishniovskiy proposed the following empirical formula:

$$G=\frac{d_{п}^{2}}{0,00233d_{п}+1,068\sigma}\mu_{0}, \qquad (4\text{-}35)$$

where $d_п$ — the diameter of the pole piece.

This formula within limits $d_п$ from 3 to 30 mm gives error not more than 2o/o.

Coefficient of scattering the pole piece

$$k_{\sigma}=\frac{G'_{\delta}}{G}=\frac{G+G_{1}+G_{2}}{G}. \qquad (4\text{-}36)$$

2. Conductivity between pole of rectangular section and hinged armature (relay of type RPN) (Fig. 4-10b) can be calculated as follows:

$$G=\int_{R_{1}}^{R_{2}}\mu_{0}\frac{b\,dx}{\alpha x}=\mu_{0}\frac{b}{\alpha}\ln\frac{R_{2}}{R_{1}}\approx\frac{bc_{1}}{\delta}\mu_{0}\ln\frac{R_{2}}{R_{1}}, \qquad (4\text{-}37)$$

where b - width of pole.

3. Conductivity between cone-shaped surfaces (Fig. 4-10, c) is equal to:

$$G=\mu_0 d\left(\frac{\pi d}{4\delta \sin^2 \alpha_1}-\frac{0{,}157}{\sin^2 \alpha_1}+0{,}75\right). \qquad (4\text{-}38)$$

c) Specific conductivities for flows of scattering.

Specific conductivity for leakage fluxes, i.e., conductivity of escape per the unit of length (1m) of the magnetic circuit between the core of cylindrical form and the in parallel arranged/located flat/plane housing (Fig. 4-11a), it is possible to calculate according to the formula:

$$g=\frac{2\pi}{\ln\frac{c+\sqrt{c^2-r^2}}{r}}\mu_0, \qquad (4\text{-}39)$$

where r - a radius of core in m and c - the distance between centers of core and housing in m.

Specific leakage conductance between two in parallel arranged/located cylindrical cores (Fig. 4-11,b)

$$g=\frac{\pi}{\ln\frac{c+\sqrt{c^2-d^2}}{d}}\mu_0, \qquad (4\text{-}40)$$

where d is a diameter of core and c - the distance between centers.

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Specific leakage conductance of the shielded relay whose coil is surrounded by cylindrical steel jacket (Fig. 4-11c),

$$g = \frac{2\pi}{\ln\frac{R}{r}}\mu_0, \qquad (4\text{-}41)$$

where R - an inside radius of jacket (screen) and r is a radius of core.

Specific leakage conductance between the average flat/plane core and two side-by-side reverse plates of the magnetic circuit of w-shaped form (Fig. 4-11d)

$$g = \left[\frac{4}{\pi}\ln\left(1 + \frac{\pi h}{2c_2}\right) + \frac{2b}{c_2}\right]\mu_0, \qquad (4\text{-}42)$$

where h is width of core, b - its thickness and c_2 - the distance between the core and plates.

The given abcve expressions can be utilized also for the calculation of the conductivities of relay with the core of rectangular section, if we substitute for h the diameter of the equivalent on perimeter section of circle.

d) Conductivity for leakage fluxes.

The flow value of scattering (escape) at the evenly distributed over entire length of core winding can be found from formula (4-25); we have:

$$\Phi_y = \Phi_{cp} - \Phi_l \approx \frac{Iw}{R_в} \cdot \frac{R_в g l}{3} = \frac{Iwgl}{3}.$$

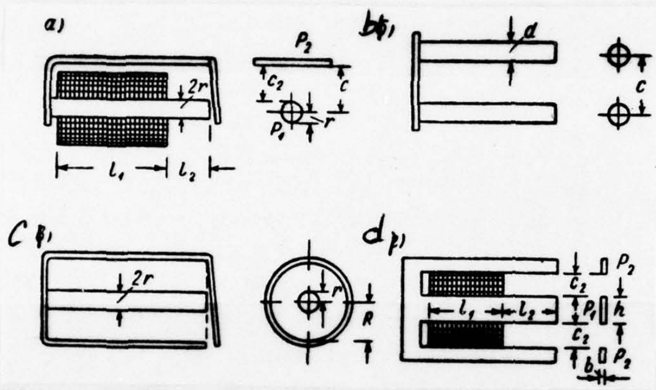

Fig. 4-11. On the calculation of conductivities of scattering: a) between cylinder and parallel plane; b) between two cylinders; c) shielded relay; d) between flat/plane core and two parallel plates.

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Hence we find for the given conductivity of leakage fluxes (escape):

$$G_y = \frac{\Phi_y}{Iw} = \frac{gl}{3}. \qquad (4\text{-}43)$$

Of some types of relay, the winding occupies not entire

length of core; in such cases the conductivity for the leakage fluxes of valve type relay (Fig. 4-11a) can be determined by the following formula:

$$G_y = \frac{g_1 l_1}{3} + g_2 l_2 + g_2 d, \quad (4\text{-}44)$$

where

$$d = \frac{p_1 + p_2}{2\pi}.$$

Here p_1 and p_2 - the perimeters of the section of core and housing, c_2 - the distance between core and housing, l_1 — the length of winding, l_2 — the length of the free end/lead of the core, not occupied with winding, g_1 - specific conductivity for leakage fluxes along the length of winding and g_2 - the same for the free end/lead of the core.

Values g_1 and g_2 depend on values d and c_2. Figures 4-12 gives dependence curves of values g_1 and g_2 from ratio D/d, where D = c_2 + d. If the magnetic circuit of relay has w-shaped form (Fig. 4-11d), then

$$G_y = 2\left(\frac{g_1 l_1}{3} + g_2 l_2 + g_2 d\right). \quad (4\text{-}44a)$$

4-6. The reluctance of the magnetic circuit of relay.

Figures 4-13 gives the equivalent diagrams of the magnetic relay circuit of valve type with circular core. The complete reluctance of this magnetic relay circuit will be equal to:

$$R'_{\text{м}} = lR_{\text{ж}} + \frac{R_g(R_{\text{в}} + R_0)}{R_0 + R_g + R_{\text{в}}}, \qquad (4\text{-}45)$$

where

$$R_g = \frac{1}{G_{\text{у}}} \quad \overset{(1)}{\text{и}} \quad R_{\text{в}} = R_\delta + R_{\text{ш}} + R_{\text{ст}}.$$

Key: (1). and.

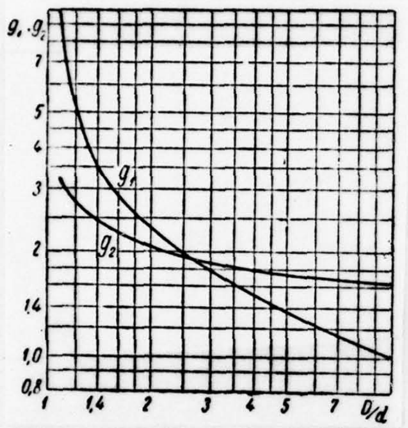

Fig. 4-12. Dependence curves of values g_1 and g_2 from ratio D/d.

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In formulas R_g — the given reluctance of the leakage paths (scattering) of magnetic flux; $R_з$ is common gap reluctance of relay taking into account the resistor/resistance of the joint of armature with body; R_δ is the reluctance of working air gap, which depends on the course of armature; $R_{от}$ — is gap reluctance, formed between armature and core with tightened armature, because of the presence of the nonmagnetic plug (plate) of loosening; R_m

is the reluctance of the air joint of body with armature of the rotational axis of the latter (value $R_{\text{ст}}$ we consider not depending on the course of armature); R_0 is the reluctance of joint of housing with core of the base of the latter and $R_{\text{мк}}$ — the average reluctance of the unit of the length of core and housing of relay.

After dividing the M.M.F. of winding for value $R'_{\text{м}}$, it is possible to find the great value of magnetic flux in the core of relay.

For determining the amount of flow of the end/lead of the core (of the pole piece) necessary to divide the M.M.F. of winding into equivalent reluctance $R_{\text{м}}$, value of which can be easily found according to equivalent diagram (Fig. 4-13a) with the aid of the Ohm and Kirchhoff laws:

$$R_{\text{м}} = R_{\text{в}} + R_0 + lR_{\text{мк}} + \frac{lR_{\text{мк}}}{R_g}(R_{\text{в}} + R_0). \qquad (4\text{-}46)$$

If we disregard the effect of leakage fluxes $(R_g = \infty)$, that expression for the reluctance of relay circuit will take the following form:

$$R_{\text{м}} = R_{\text{в}} + R_0 + lR_{\text{мк}} = R_\delta + R_{\text{п}}, \qquad (4\text{-}46\text{a})$$

where $R_{\text{п}}$ is a sum of the reluctances of the cell/elements

of the magnetic circuit whose value they do not in practice depend on the course of the armature:

$$R_{п} = lR_{ж} + R_{0} + R_{ст} + R_{ш}. \tag{4-47}$$

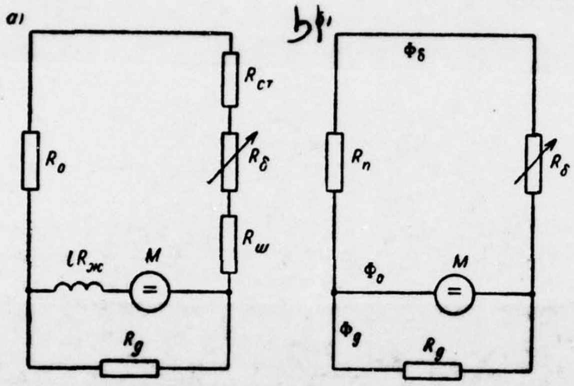

Fig. 10 Fig. 4-13. Equivalent diagram of magnetic relay circuit of valve type.

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The reluctance of the working air gap

$$R_\delta = \frac{1}{G_\delta} = \frac{1}{G_\delta'} - R_m = R_\delta' - R_m, \qquad (4\text{-}48)$$

where R_δ' is common/general/total magnetic resistance of working gap taking into account the plug of loosening.

If we disregard reluctance they became core and

housings $(R_{ж} = 0)$, that complete reluctance of relay circuit

$$R_{м} = \frac{R_g(R_в + R_0)}{R_в + R_0 + R_g} = \frac{R_g(R_п + R_\delta)}{R_g + R_п + R_\delta} = \frac{R_g(\mu_0 S R_п + \delta)}{\mu_0 S(R_g + R_п) + \delta}. \quad (4\text{-}45a)$$

Formulas for determining permeance in the different cases are given in [4-4, 4-5, 4-6, 4-14, 4-15, 4-19, 4-22, 4-28, 4-33].

4-7. Inductance of relay.

The value of magnetic flux along the length of the magnetic circuit of relay is variable due to the presence of leakage fluxes. If we disregard the reluctance of the joint of core with housing ($R_0 = 0$), then flow value Φ_x in the section, distant at a distance of x from the base of relay, can be calculated with the aid of (4-15). On the section of core dx, the flow Φ_x is coupled with number of turns $\frac{w}{l}dx$; the number of flux linkages on this section is equal to:

$$d\Psi = \Phi_x \frac{w}{l} dx.$$

Total number of flux linkages of the relay

$$\Psi = \int_0^l \Phi_x \frac{w}{l}\, dx = \int_0^l \Phi_l \left[1 + \frac{qR_в}{lR_ж}\left(1 - \frac{\operatorname{ch} x\sqrt{gR_ж}}{\operatorname{ch} l\sqrt{gR_ж}}\right)\right]\frac{w}{l}\, dx =$$
$$= \Phi_l \frac{w}{l}\left(l + \frac{qR_в}{R_ж} - \frac{qR_в \operatorname{th} l\sqrt{gR_ж}}{lR_ж\sqrt{gR_ж}}\right) = \Phi_l w\left[1 + \frac{R_в}{lR_ж}(q-1)\right].$$

On the other hand, as is known, the value of static inductance is determined from the relationship/ratio:

$$L_0 = \frac{\Psi}{I} = \frac{\Phi_l w}{I}\left[1 + \frac{R_в}{lR_ж}(q-1)\right].$$

Substituting in this expression for Φ_l and q of their value from equations (4-14) and (4-14a), we obtain formula for the static inductance of relay (during steady-state conditions/mode):

$$L_0 = \frac{w^2}{lR_ж + qR_в}\left(1 + \frac{R_в g l}{3}\right) = \frac{3 + R_в g l}{3(lR_ж + qR_в)} w^2 = K_0 w^2, \quad (4\text{-}49)$$

where K_0 - the given inductance of one turn in H.

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Value K_0 is given permeance of the relay:

$$K_0 = \frac{1}{lR_{ж} + qR_в}\left[1 + \frac{R_в}{lR_{ж}}(q-1)\right] = \frac{3 + R_в gl}{3(lR_{ж} + qR_в)} = \frac{1}{R_м}. \quad (4\text{-}50)$$

In this formula $R_м$ - the given reluctance:

$$R_м = \frac{lR_{ж} + qR_в}{1 + \frac{R_в}{lR_{ж}}(q-1)} = \frac{3(lR_{ж} + qR_в)}{3 + R_в gl}. \quad (4\text{-}51)$$

Disregarding the resistance of steel, we obtain:

$$L_0' = \frac{1}{R_в}\left(1 + \frac{R_в gl}{3}\right)w^2. \quad (4\text{-}49a)$$

If we consider the reluctance of the joint of core with housing R_0, then

$$L_0 = \frac{(2 + R_0 gl)(3 + R_в gl)\,w^2}{6\left[(R_{ж} + R_в R_0 g)\,l + q(R_0 + R_в)\right]} = K_0' w^2. \quad (4\text{-}52)$$

Disregarding conductivity for leakage fluxes ($g \approx 0$), we obtain:

$$L_0'' = \frac{w^2}{lR_{ж} + R_0 + R_в} = K_0'' w^2. \quad (4\text{-}52a)$$

Value K_0 depends on the construction of relay, size/dimensions of clearance and magnetizing ampere-turns.

Determination K_0 from the given above formula (4-50) is simple, but it requires sufficiently much time; therefore for a standard relay to considerably conveniently use experimental materials.

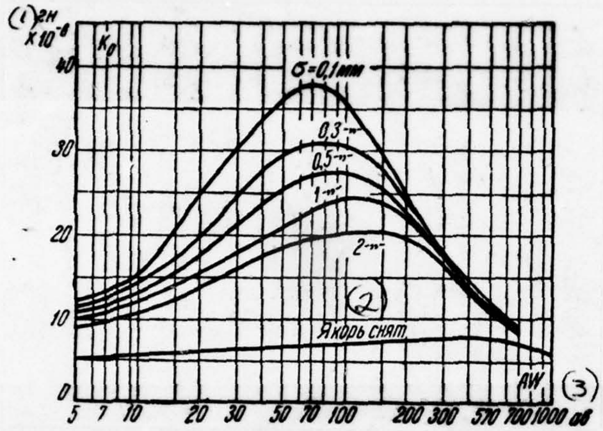

Fig. 4-14. Curves K_0 for relay of type RPN.

Key: (1). H. (2). Armature is removed. (3). AV.

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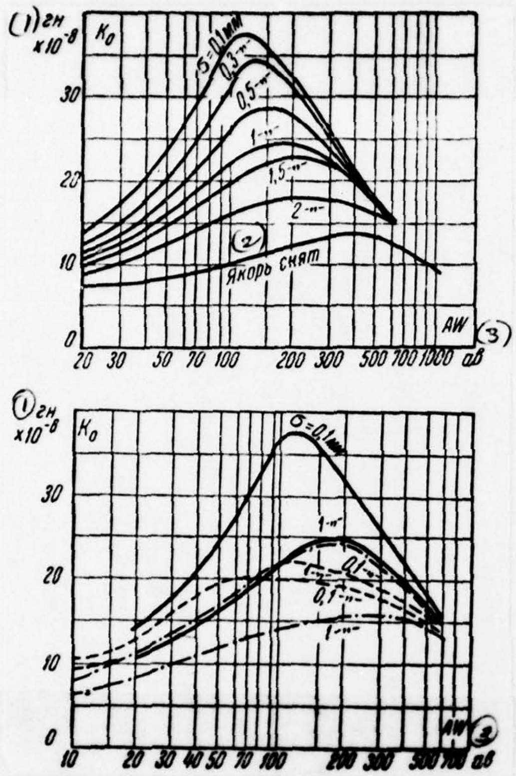
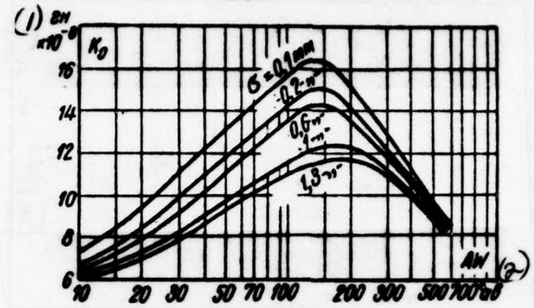


Fig. 4-15. Curves K_0 for relay of type RKN; continuous - relay normal; dotted line - pulse; dotted line with point is test.

Key: (1). H. (2). Armature is removed. (3). AV.

Fig. 4-16. Curves K_0 for relay of type RKM-1.



Key: (1). H. (2). AV.

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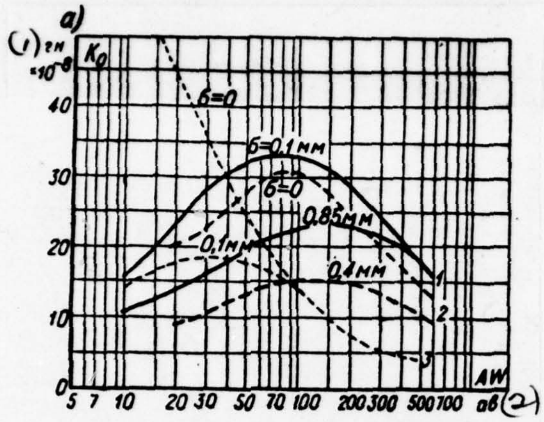
Figures 4-14, 4-15, 4-16, 4-17 and 4-18 give the curves of dependences K_0 on ampere-turns for the relay of types RPN, RKN, RKM-1, RKMP, RMU, RS-13, RES6, etc. with different clearances, obtained experimentally. The measurements of inductance were conducted by ballistic method by the means of Maxwell's bridge by direct current.

From these curves it follows that the inductance of relay has a maximum approximately within limits from 70 to 200 ampere-turns.



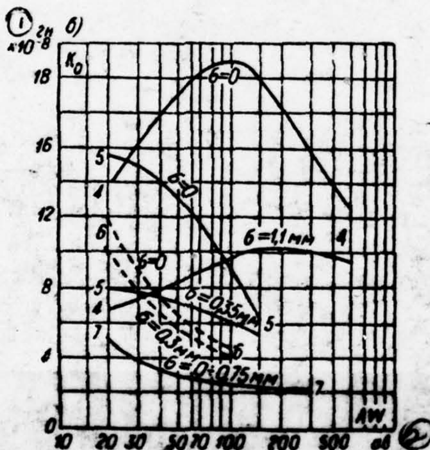


Fig. 4-17. Curves K_0 for relay. 1 type RKMP; 2 - the type RMU; 3 - the type RDCG; 4 - the type RS-52; 5 - the type RES10; 6 - the type RES15; 7 - the type RPS20.

Key: (1). H. (2). A.V.

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In the magnetizing field of more than 300 ampere-turns, the inductance barely depends on the value of clearance. The inductance of pulse and test relays of the type RKN is considerably less than the inductance of normal relays, the inductance of pulse relays due to the saturation of the neck of armature in practice not depending on the value of clearance.

The inductance of coils without steel core can be determined with error several percentages with the aid of the following approximation formulas: a) for crossover coils which have $0 < D < p$,

$$L = 10{,}1 w^2 D \sqrt[3]{\left(\frac{D}{p}\right)^2} \cdot 10^{-9} \ \overset{(1)}{[гн]}; \qquad (4\text{-}53)$$

Key: (1). H.

b) for pancake coils, for which $p < D < 3p$,

$$L = 10{,}1 w^2 D \sqrt{\frac{D}{p}} \cdot 10^{-9} \ \overset{(1)}{[гн]}; \qquad (4\text{-}54)$$

Key: (1). H.

where D is the mean diameter of coil and p - the perimeter of the sectional area of winding in cm.

4-8. Magnetic energy and attracting force.

For the case of the switching on of magnet winding on direct/constant voltage, it is possible to write the following equation:

$$U = iR + \frac{d\Psi}{dt}.$$

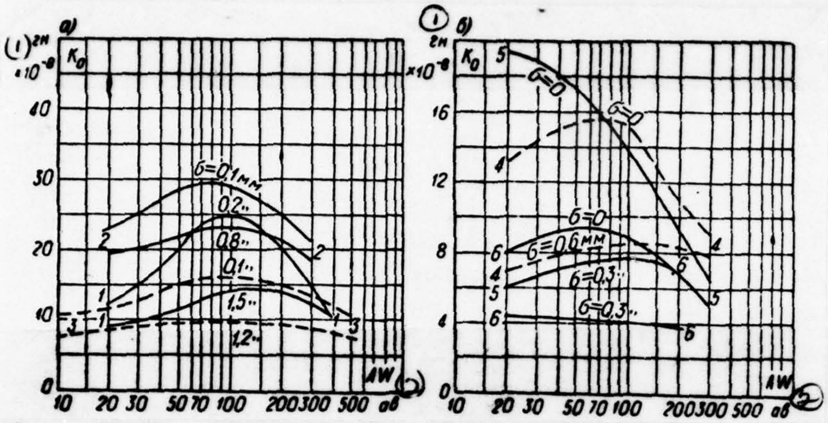

Fig. 4-18. Curves K_0 for relay. 1 - the type RES14; 2 - type RES8; 3 - the type RS-13; 4 - type RES6; 5 - the type RES22; 6 - type RES9.

Key: (1). H. (2). AV.

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After multiplying both parts of the equation on i, it is possible the total energy balance of electric magnet to present in the form

$$\int_0^t Ui\,dt - \int_0^t i^2 R\,dt = \int_0^\Psi i\,d\Psi,$$

i.e. the energy, which entered from grid/network for time t minus of heat losses, is converted into magnetic energy of the electromagnet:

$$W = \int_0^{\Psi} i d\Psi. \qquad (4\text{-}55)$$

Graphically this energy is expressed by the area, limited by the curve of flux linkages and by the axis of ordinates.

Figures 4-19a, shows the curves of the dependences of the flux linkages of electromagnet on current with unpulled δ_1 and pulled δ_2 positions of armature.

A change in the flux linkages during the motion of armature is characterized by the curve a_1a_2.

Let us examine the energy balance in electromagnet during armature travel.

Magnetic energy, stored up in system at the beginning of the motion of armature,

$$W_1 = \int_0^{\Psi_1} i d\Psi = \text{area } Oa_1b_1.$$

The magnetic energy, obtained by the system for the time of the motion of armature,

$$W_2 = \int_{\Psi_1}^{\Psi_2} i d\Psi = \text{area } a_1b_1b_2a_2.$$

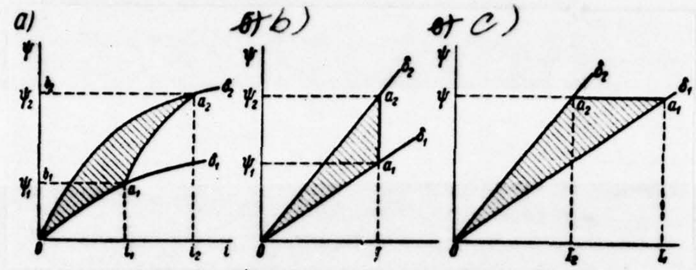

Fig. 4-19. Curved of dependences of flux linkages of electromagnet on current.

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The magnetic energy, stored up (remaining) in system after the termination of the motion of the armature

$$W_3 = \int_0^{\Psi_2} i d\Psi = \text{area } Oa_2b_2.$$

The magnetic energy, expended for armature travel, is defined as difference between the supplied to system and that which is remaining after the termination of the motion of armature by the magnetic energy:

$$W_м = W_1 + W_2 - W_3. \quad (4\text{-}56)$$

Graphically this energy is expressed by shaded area Oa_1a_2O.

The attracting force (thrust/rod) of the armature of electromagnet and torque can be expressed by the following formulas:

$$F = -\frac{dW_M}{d\delta} \tag{4-57}$$

and

$$M_e = -\frac{dW_M}{d\alpha}, \tag{4-57a}$$

where α is an angle of rotation of armature.

Minus sign indicates that the work is conducted because of decrease of magnetic energy of electromagnet.

As a result of nonlinearity of the curves of magnetization of relay, the attracting force can be agreed to only by graphic path. However, if we allow that the magnetic characteristics of relay are rectilinear (μ = const) and the current strength for the time of the motion of armature does not change (Fig. 4-19b), then for attracting force it is possible to obtain analytical expression. Then

$$W_M = \frac{1}{2} I\Psi_1 + I(\Psi_2 - \Psi_1) - \frac{1}{2} I\Psi_2 = \frac{1}{2} I(\Psi_2 - \Psi_1).$$

In the case of small scattering $\Psi = \Phi w$; we obtain the following expression:

$$F = -\frac{1}{2} I \frac{d\Psi}{d\delta} = -\frac{1}{2} Iw \frac{d\Phi}{d\delta} = -\frac{(Iw)^2}{2} \cdot \frac{dG_M}{d\delta}.$$

Torque of armature (traction torque/moment)

$$M_e = -\frac{(Iw)^2}{2} \cdot \frac{dG_M}{d\alpha}.$$

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General permeance of the relay

$$G_M = \frac{1}{\frac{1}{G_\delta} + \frac{1}{G_n}} \text{ и } \frac{dG_M}{d\delta} = \frac{G_M^2}{G_\delta^2} \cdot \frac{dG_\delta}{d\delta},$$

where G_δ is general permeance of working air gap, which depends on the angle of rotation of armature, and G_n - permeance of the remaining sections of the magnetic circuit of relay (core, bodies, bases, armature, joints and plug), which does not depend on the angle of rotation of armature. Consequently,

$$F = -\frac{AW^2 G_M^2}{2G_\delta^2} \cdot \frac{dG_\delta}{d\delta}. \qquad (4\text{-}58)$$

Then torque (traction torque/moment)

$$M_\text{э} = -\frac{AW^2}{2} \cdot \frac{dG_M}{d\alpha} = -\frac{AW^2 G_M^2}{2G_\delta^2} \cdot \frac{dG_\delta}{d\alpha}. \qquad (4\text{-}58a)$$

But if we assume that for the time of the motion of armature the value of flux linkages does not change and the magnetic characteristics of relay are rectilinear (Fig. 4-19c), then, disregarding scattering, we obtain:

$$W_M = \frac{1}{2} I_1 \Psi - \frac{1}{2} I_2 \Psi = \frac{1}{2} \Psi (I_1 - I_2) = \frac{1}{2} \Phi^2 (R_{M1} - R_{M2}).$$

In this case the attracting force will be expressed by the following formula:

$$F = \frac{\Phi^2}{2} \cdot \frac{dR_M}{d\delta} \qquad (4\text{-}59)$$

and the torque of the armature:

a) The attracting force of relay with the pole of round cross-section and hinged armature.

$$M_э = \frac{\Phi^2}{2} \cdot \frac{dR_м}{d\alpha}. \qquad (4\text{-}59a)$$

General permeance of working air gap according to formulas (4-28), (4-29) and (4-30) [4-10]:

$$G'_\delta = G + G_1 + G_2 \quad и \quad \frac{dG'_\delta}{d\alpha} = \frac{dG}{d\alpha} + \frac{dG_1}{d\alpha} + \frac{dG_2}{d\alpha},$$

where

$$\frac{dG}{d\alpha} = -\frac{2\pi\mu_0}{\alpha^2}\left(c_1 - \sqrt{c_1^2 - r^2}\right),$$

$$\frac{dG_1}{d\alpha} = \frac{\pi^2\mu_0 c_1}{2\left(\frac{\pi}{2}+1\right)^2 \cos^2\alpha}$$

and

$$\frac{dG_2}{d\alpha} = -\frac{2ar\mu_0\left[R_1\left(\frac{a}{2}+R_2\,\mathrm{tg}\,\alpha\right)+R_2\left(\frac{a}{2}+R_1\,\mathrm{tg}\,\alpha\right)\right]}{\cos^2\alpha\sqrt{\left(\frac{a}{2}+R_1\,\mathrm{tg}\,\alpha\right)^3\left(\frac{a}{2}+R_2\,\mathrm{tg}\,\alpha\right)^3}}.$$

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In the particular case, when it is possible to disregard the affect of permeance of the paths of the boundary/edge and lateral flows of pole and conductivity $G_п$, for the torque of the armature of relay, we obtain:

$$M_э = -\frac{(Iw)^2}{2} \cdot \frac{dG}{d\alpha} = \frac{AW^2\pi\mu_0}{\alpha^2}\left(c_1 - \sqrt{c_1^2 - r^2}\right).$$

Substituting for AW² their value Φ^2/G^2, we find:

$$M_э = \frac{\Phi^2}{4\pi\mu_0\left(c_1 - \sqrt{c_1^2 - r^2}\right)}. \qquad (4\text{-}60)$$

At the small angles of rotation of armature, it is possible to count $\alpha \approx \delta/c_1$; then

and

$$G = \frac{2\pi c_1}{\delta}\mu_0 (c_1 - \sqrt{c_1^2 - r^2})$$
$$\frac{dG}{d\delta} = -\frac{2\pi c_1}{\delta^2}\mu_0 (c_1 - \sqrt{c_1^2 - r^2}).$$

The tightening force, applied to armature (against the center of core), will be equal to:

$$F = \frac{AW^2}{2}\cdot\frac{2\pi c_1\mu_0}{\delta^2}(c_1 - \sqrt{c_1^2 - r^2}) = \frac{\Phi^2}{4\pi c_1\mu_0 (c_1 - \sqrt{c_1^2 - r^2})}. \quad (4\text{-}60a)$$

During practical calculations by the effect of permeance of the paths of boundary/edge and lateral flows and conductivity G_n cannot be disregarded, since this is led to large errors.

b) The attracting force of relay with the rectangular cross section of pole and hinged armature.

If we disregard the effect of the conductivity of the paths of the boundary/edge and lateral flows of pole, and also the effect of conductivity G_n, for the torque and attracting force we will obtain the following approximations:

$$M_e = \frac{AW^2}{2\alpha^2}\cdot b\mu_0 \ln\frac{R_2}{R_1} = \frac{\Phi^2}{2b\mu_0 \ln\frac{R_2}{R_1}}; \quad (4\text{-}61)$$

$$F = \frac{\Phi^2}{2bc_1\mu_0 \ln\frac{R_2}{R_1}}. \quad (4\text{-}61a)$$

Virtually these formulas also give large errors.

$$G_\delta = \frac{S}{\delta}\mu_0 \text{ and } \frac{dG_\delta}{d\delta} = -\frac{S}{\delta^2}\mu_0 = \frac{G_\delta^2}{\mu_0 S}.$$

c) Attracting force with small working gaps.

In the particular case when the value of working interiron space is low in comparison with the area of the pole of core and magnetic circuit is not saturated, is possible to accept according to formula (4-27):

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In this case from (4-58) we obtain for attracting force the following expression:

$$F = \frac{AW^2 G_M^2 S}{2G_\delta^2 \delta^2}\mu_0 = \frac{AW^2 G_\Pi^2 S}{2(G_\Pi + G_\delta)^2 \delta^2}\mu_0 = \frac{AW^2 G_M^2}{2\mu_0 S}. \qquad (4\text{-}62)$$

Total magnetic conductivity, if we disregard the effect of leakage fluxes, will be:

$$G_M = \frac{1}{R_M} = \frac{1}{R_\Pi + R_\delta}.$$

Substituting in expression (4-62) instead of G_M its value, we obtain:

$$F = \frac{AW^2}{2\mu_0 S (R_\Pi + R_\delta)^2} = \frac{\Phi^2}{2\mu_0 S} = \frac{B^2 S}{2\mu_0}\ [\text{н}]. \qquad (4\text{-}62a)$$

With the tightened armature $R_\delta = 0$ the attracting force

$$F_{\delta 0} = \frac{AW^2}{2\mu_0 S R_\Pi^2} = \frac{\Phi_{\delta 0}^2}{2\mu_0 S}. \qquad (4\text{-}62b)$$

The relation of magnetic flows in untightened and tightened positions of armature is equal to:

$$\frac{\Phi}{\Phi_{\delta 0}} = \frac{R_{\text{п}}}{R_{\text{п}} + R_{\delta}} = \frac{\mu_0 S R_{\text{п}}}{\mu_0 S R_{\text{п}} + \delta},$$

whence

$$\Phi = \Phi_{\delta 0} \frac{\mu_0 S R_{\text{п}}}{\mu_0 S R_{\text{п}} + \delta}.$$

After substituting into equation (4-62a) instead of Φ its value, we obtain:

$$F = \frac{\Phi_{\delta 0}^2 (\mu_0 S R_{\text{п}})^2}{2\mu_0 S (\mu_0 S R_{\text{п}} + \delta)^2} = F_{\delta 0} \frac{(\mu_0 S R_{\text{п}})^2}{(\mu_0 S R_{\text{п}} + \delta)^2} \text{ [н]}. \quad (4\text{-}63)$$

If we express size/dimensions in cm, flow in the Maxwell and substitute $\mu_0 = 4\pi \cdot 10^{-7}$ H/m, then

$$F = \frac{0{,}02\pi \cdot AW^2 \cdot 10^{-8}}{981 \cdot S (R_{\text{п}} + R_{\delta})^2} = 6{,}4 \cdot 10^{-8} \frac{AW^2}{S (R_{\text{п}} + R_{\delta})^2} = \frac{\Phi^2 \cdot 10^{-8}}{8\pi \cdot 981 \cdot S} = 4{,}06 \cdot 10^{-8} B^2 S \text{ [кГ]}^{(1)} \quad (4\text{-}63а)$$

Key: (1). kgf.

or

$$F = \frac{\Phi_{\delta 0}^2 \cdot 10^{-8} \cdot S^2 R_{\text{п}}^2}{8\pi \cdot 981 \cdot S (S R_{\text{п}} + \delta)^2} = F_{\delta 0} \frac{S^2 R_{\text{п}}^2}{(S R_{\text{п}} + \delta)^2} \text{ [кГ]}^{(1)}. \quad (4\text{-}63б)$$

Key: (1). kgf.

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If we consider the effect of leakage fluxes and disregard magnetic resistor/resistance of steel magnetic circuit ($R_{м} = 0$), then, according to the equivalent diagram of magnetic relay circuit (Fig. 4-13b), it is possible to write:

$$\Phi_\delta (R_\delta + R_п) = \Phi_0 \frac{R_g (R_\delta + R_п)}{R_g + R_\delta + R_п},$$

whence

$$\Phi_\delta = \frac{\Phi_0 R_g}{R_g + R_\delta + R_п} = \frac{\Phi_0 R_g}{R_g + R_п + \frac{\delta}{\mu_0 S}}.$$

After substituting into equation (4-62a) instead of $\Phi = \Phi_\delta$ its value, we obtain:

$$F = \frac{\Phi_0^2 (\mu_0 S R_g)^2}{2\mu_0 S [\mu_0 S (R_п + R_g) + \delta]^2} \ [н] \qquad (4\text{-}64)$$

or

$$F = \frac{\Phi_0^2 S^2 R_g^2 \cdot 10^{-8}}{8\pi \cdot 981 \cdot S [S (R_п + R_g) + \delta]^2} \ [кГ]. \qquad (4\text{-}64a)$$

Below in § 4-12, it is shown, that the work of electromagnet reaches the greatest value when $R_\delta = R_п$.

Consequently, in the case of the optimum relationship/ratio of the reluctances of the individual sections of magnetic circuit formula for attracting force will take the following form:

$$F_{опт} = \frac{AW^2}{8\mu_0 S R_п^2} = \frac{AW^2 S}{8\delta^2} \mu_0 \ [н] \qquad (4\text{-}65)$$

or

$$F_{опт} = 1{,}6 \cdot 10^{-8} \frac{AW^2}{SR_п^2} = 1{,}6 \cdot 10^{-8} \frac{AW^2 S}{\delta^2} \ [кГ]. \qquad (4\text{-}65a)$$

For the calculation of the attracting force of relay with relatively larger clearances, it is possible to use also formula (4-62b), if we introduce the empirical correction factor of a, which considers the nonuniformity of flow distribution in clearance and the effect of the

boundary/edge and lateral flows of pole. Then expressions for attracting force will take the form

$$F = \frac{\Phi_\delta^2}{2\mu_0 S(1 + 100a\delta)}\ [н]; \qquad F = \frac{4{,}06 \cdot 10^{-8} \Phi_\delta^2}{S(1 + a\delta)} = \frac{4{,}06 \cdot 10^{-8} \cdot B_\delta^2 S}{1 + a\delta}\ [кГ]. \tag{4-66}$$

where **a is the coefficient, depending on** the type (form) of magnetic circuit, its size/dimensions, the values of magnetic induction and size/dimensions of clearance.

Experimental investigations showed that for relay with circular core coefficient a was equal to example 5 and its value can be considered depending cn induction (when saturation), the size/dimensions of core and value of clearance are absent,.

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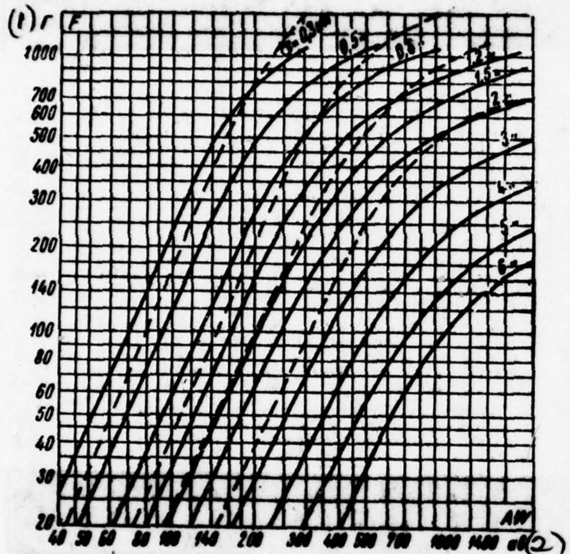

Fig. 4-20.

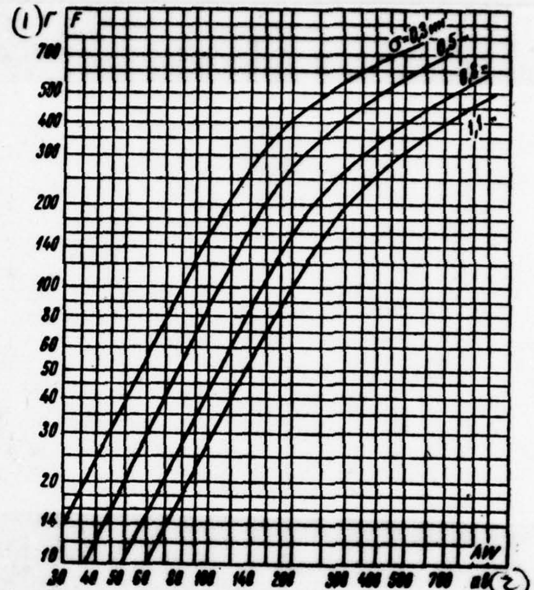

Fig. 4-21

Fig. 4-20. The full-load saturation curves of relay of the type RKN; solid lines - with the pole piece; broken - without the pole piece (a/b = 0.93).

Key: (1). g. (2). AV.

Fig. 4-21. Full-load saturation curves of relay of type RKM-1.

Key: (1). g. (2). AV.

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For relay with flat core of the type RPN coefficient a depends on the course of armature; at clearance 0.9-1.3 mm, the value of coefficient a is approximately equal to 3.9.

4-9. Load and electromechanical (traction) characteristics.

a) Full-load saturation curves.

The relationship between attracting force of the armature of relay and ampere-turns at the constant value of interiron space is called load characteristic. In the particular case, if we disregard saturation of steel of magnetic circuit and the effect of leakage fluxes, attracting force, according to formula (4-65a), will be equal to:

$$F = 1{,}6 \cdot 10^{-8} \frac{AW^2}{\delta^2} S.$$

Consequently, with the relatively low value of clearance and the optimum relationship/ratio of reluctances $R_м$ and R_δ attracting force at the constant value δ is proportional to the square of ampere-turns.

Depending on value and shape of surface of pole and armature, the law of a change in the conductivity of clearance during armature travel can change its character. The respectively full-load saturation curves of relay can have the most diverse form.

In Fig. 4-20, 4-21, 4-22, 4-23 and 4-24 are provided load characteristics of some types of electromagnetic relays, used in equipment for automation and communication. From these characteristics it follows that for producing of a comparatively small attracting force 10 g with a small clearance 0.2 mm is necessary the sufficiently significant magnitude M.M.F. - about 30 AV.

Comparative full-load saturation curves of these types cf relay are shown in Fig. 1-24.

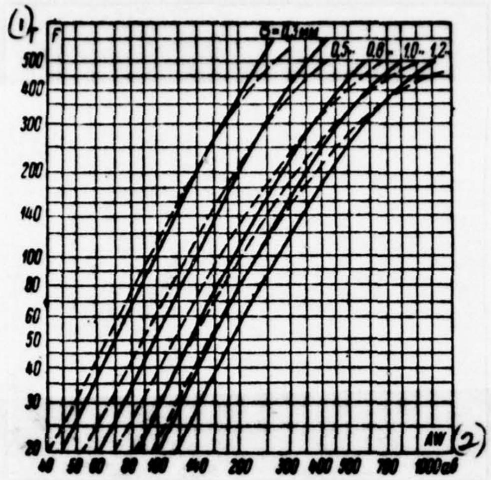

Fig. 4-22. Full-load saturation curves of relay of type RS-13; solid lines - without pole piece; broken - with pole piece.

Key: (1). g. (2). AV.

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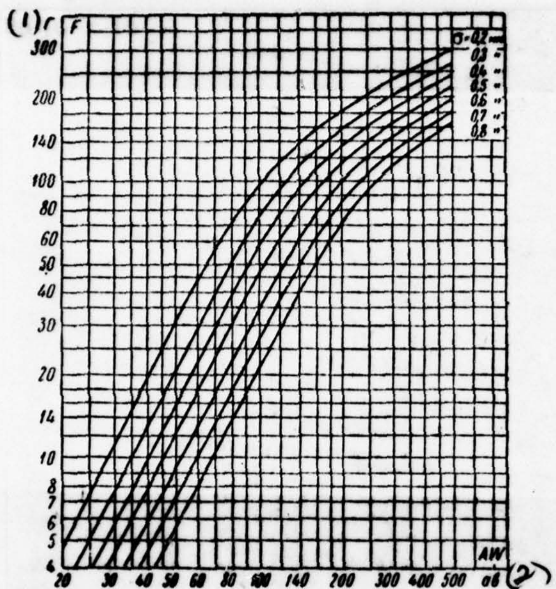

Fig. 4-23.

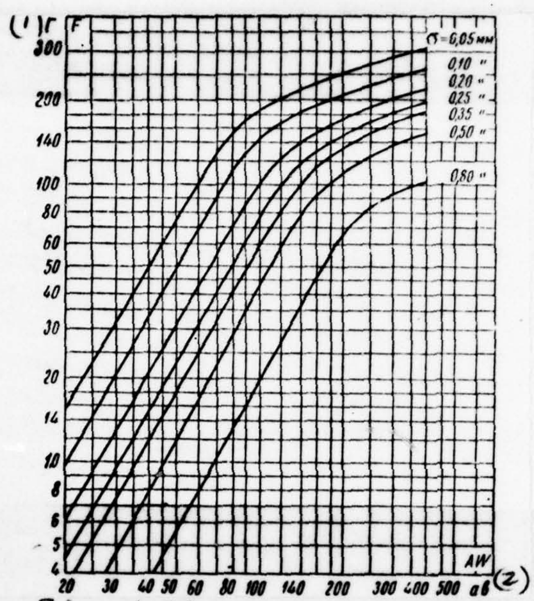

Fig. 4-24.

Fig. 4-23. Load characteristics of relay of the type RSM (a/b = 1.25).

Key: (1). g. (2). AV.

Fig. 4-24. Full-load saturation curves of relay of type RES10 (a/b = 0.83).

Key: (1). g. (2). AV.

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b) Electromechanical (traction) characteristics.

The dependence of the attracting force of armature on the value of clearance at constant ampere-turns is called the electromechanical or thrust characteristics of relay. From formula (4-65) it follows that when the effect of saturation is absent, they stopped and to the relatively low value of clearance of attracting force at constant amps-turns it is possible to count the inversely proportional to square value of interpiece space. By changing value and the pole-piece configuration and armature, it is possible to strongly change electromechanical characteristic. Figures 4-25 shows the family of the electromechanical characteristics of relays of the type RKN, obtained at the different values of ampere-turns. Dotted line in Fig. 4-25 plotted/applied the mechanical characteristic this same of the relay, loaded by two contact groups.

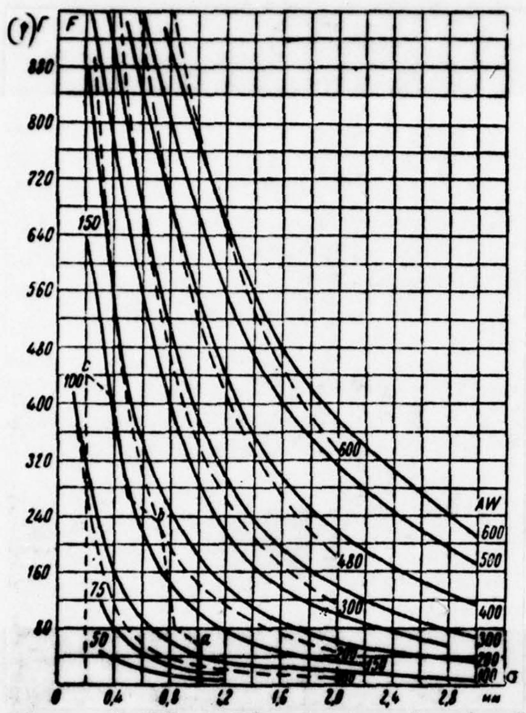

Fig. 4-25. Electromechanical characteristics of relay of the type RKN.

Key: (1). g.

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If we increase ampere-turns, then at some of their value $AW_{тр}$ the value of thrusts will become equal mechanical (in point a), and with a further increase in the ampere-turns,

the armature of **relay** will begin to move. This value of the ampere-turns $AW_{тр}$ is called the ampere-turns of the contact/start of relay with activation.

Relay will actuate/operate completely only when the attracting force of armature in all way of its displacement/movement will be more than controlling force of mechanical load. Therefore the electromechanical characteristic, corresponding to the ampere-turns of activation of relay, must lie/rest higher than mechanical characteristic of this relay. From Fig. 4-25 it follows that the ampere-turns of function (attraction) of relay are determined not by the initial or final load of armature, but by a large part of the intermediate load, corresponding to the projections of mechanical characteristic. The point of contact of tangency b of the mechanical and electromechanical characteristics of relay is called critical point, and the corresponding to it ampere-turns $AW_{ср}$ are called of critical ampere-turns or ampere-turns of function.

In certain cases critical point can coincide with point a of mechanical characteristic.

For decrease of the ampere-turns of function and weakening of the impact of armature against core desirable to match between themselves the mechanical and electromechanical characteristics of relay (i.e. the angles of the slope of these characteristics and their ordinate must be as far as possible approximated to each other).

For the start (contact/start) of the armature of relay with release/tempering, it is necessary to decrease the ampere-turns down to value $AW'_{тр}$ (ampere-turns of contact/start with release), with which electromechanical (traction) characteristic is passed through the end point c of mechanical characteristic.

To initial position the armature of relay will return at the value of ampere-turns $AW_{от}$, by which electromechanical characteristic concerns the second critical point a of mechanical characteristic. This value of ampere-turns $AW_{от}$ is called the ampere-turns of the release/tempering of relay.

The thrust characteristics of the different types of electromagnetic relays at power 0.2 W are given in Fig. 1-25.

4-10. Empirical formulas for an attracting force.

a) Attracting force on the straight portion of load characteristic.

The calculation of the attracting force of the armature of relay by analytical method taking into account real magnetic flux distribution in magnetic circuit and in working air gap, and also taking into account the effect of magnetic resistance of steel of magnetic circuit is extremely complex and requires too much time.

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Therefore lower on the base of the study of the experimental full-load saturation curves of large quantity of the specimen/samples of the relay of different size/dimensions are derive/concluded the approximation empirical formulas for the engineering calculations of attracting force, which make it possible to consider the effect of diameter and length of core.

Valve type relay.

For the execution of this work, were made 17 specimen/samples of the magnetic systems of valve type relay with the different cores, having diameters 3; 4, 5; 6; 8; 9; 10; 13 and 14 mm length 22, 35 and 76 mm, and also six the magnetic systems, having cores as diameter 3; 4, 5; 6; 8 mm with the pole pieces by diameter 7; 8; 9 and 12 mm.

For the production of these specimen/samples of relay, were used the magnetic systems and the armature of relay of type 100 (with the suspension of armature on two bronze plugs, pressed into the end surface of housing) [1-14].

In these specimen/samples of the magnetic systems of relay, they were obtained experimentally of the dependence of the attracting force of armature on the magnetizing ampere-turns (full-load saturation curve) with the different values of working air gap (0.3; 0.5; 0.7; 0.9; 1.2 and 1.5 mm).

Load was suspended to the bridge of armature; the relation of the arms of bridge and armature was equal to 1.42.

Full-load saturation curves for all tested specimen/samples of magnetic systems here is not possible to give, since them very there are many. Therefore Fig. 4-26, 4-27 and 4-28 give the families of full-load saturation curves only for three specimen/samples of the relays, which have cores as diameter 3; 4.5 and 8 mm by dyne, correspondingly, 22, 35 and 76 mm, but in Fig. 4-29, 4-30 and 4-31 dependences of the attracting force of armature on the magnetizing ampere-turns for relay with different diameters and the length of cores with the value of working air gap 0.9 mm. The full-load saturation curves of the specimen/samples of the relays, which have core with the pole pieces, are constructed by dotted lines. The size/dimensions of these cores are designated in fraction; in numerator is given the diameter of core, and in denominator - a diameter of the pole piece.

From the provided characteristics it follows that the curves of the dependences of attracting force on magnetizing ampere-turns (on logarithmic scale) on the calculated working section of characteristic are the virtually direct/straight parallel lines which during the appearance of saturation of steel of magnetic circuit begin to be bent.

The greatest calculated attracting force of the armature of relay, i.e., the limiting value of the attracting force F_m. with increase in which the full-load saturation curve begins to be bent, depends on the diameter of core and length of working air gap.

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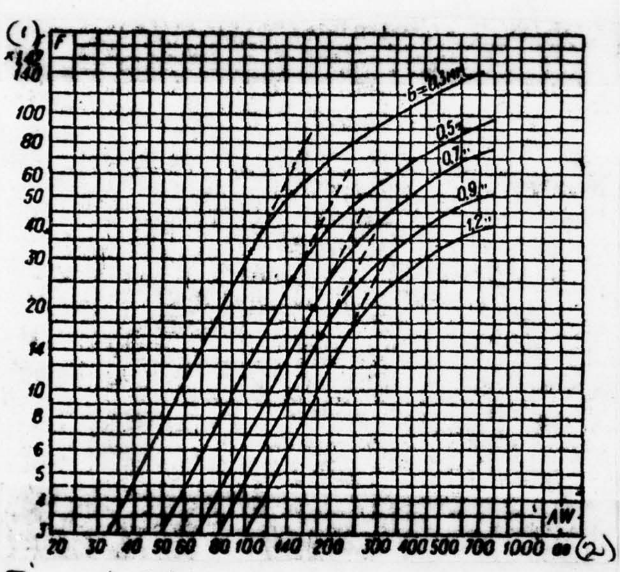

Fig. 4-26.

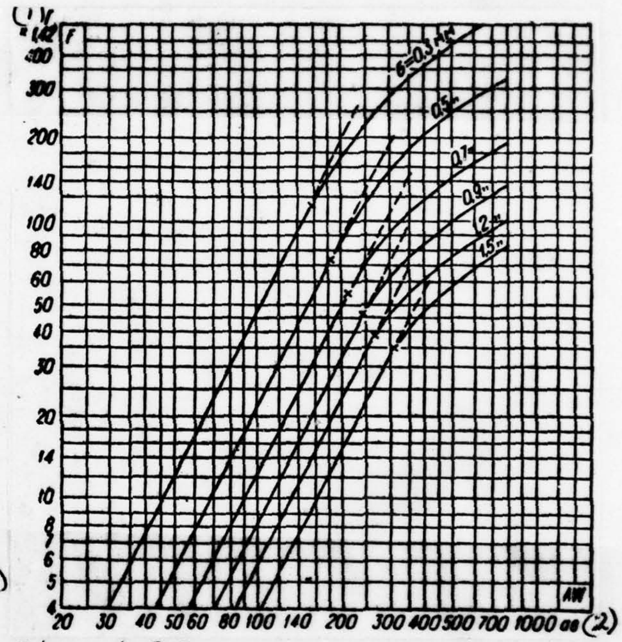

Fig. 4-27.

Fig. 4-26. full-load saturation curves of magnetic system of relay.

$d_c = 3$ мм; $l = 22$ мм.

Key: (1). g. (2). AV.

Fig. 4-27. Full-load saturation curves of magnetic system of relay.

$d_c = 4,5$ мм; $l = 35$ мм.

Key: (1). g. (2). AV.

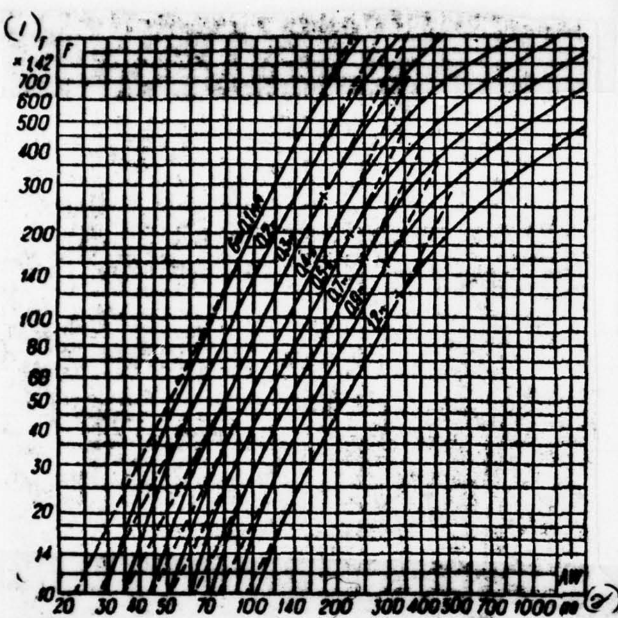

Fig. 4-28.

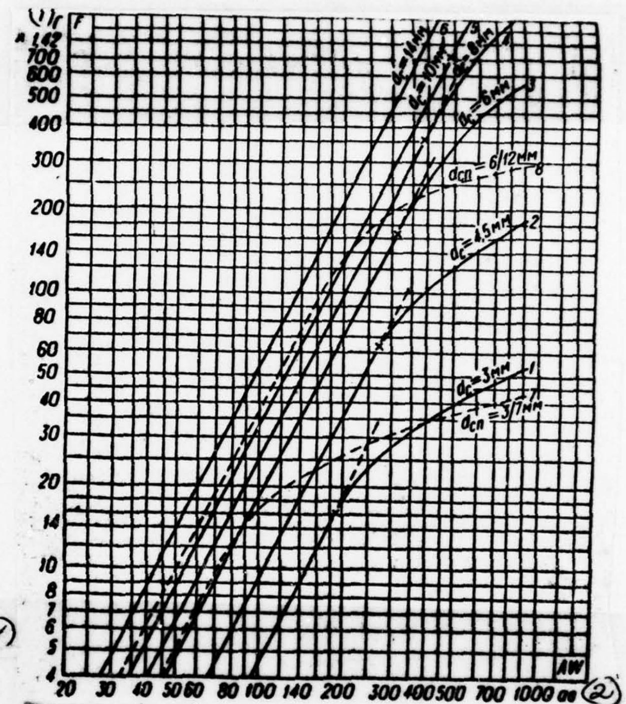

Fig. 4-29.

Fig. 4-28. The full-load saturation curves of the magnetic system of relay.

d_c = 8 мм; l = 70 мм.

Key: (1). g. (2). AV.

Fig. 4-29. Curves of dependences of attracting force on magnetizing ampere-turns with l = 22 mm and σ = 0.9 mm

1 — d_c = 3 мм; 2 — d_c = 4,5 мм; 3 — d_c = 6 мм; 4 — d_c = 8 мм; 5 — d_c = 10 мм; 6 — d_c = 14 мм; 7 — $d_{cп}$ = 3/7 мм; 8 — $d_{cп}$ = 6/12 мм.

Key: (1). g. (2). AV.

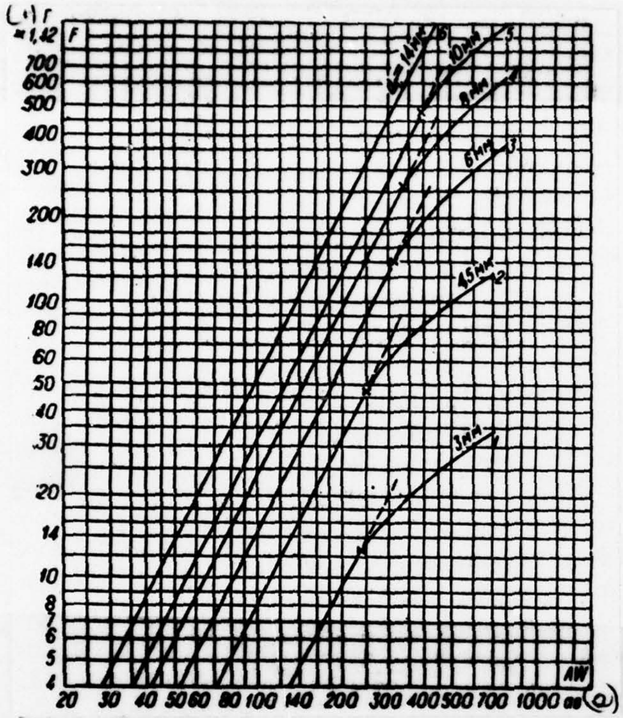

Fig. 4-30.

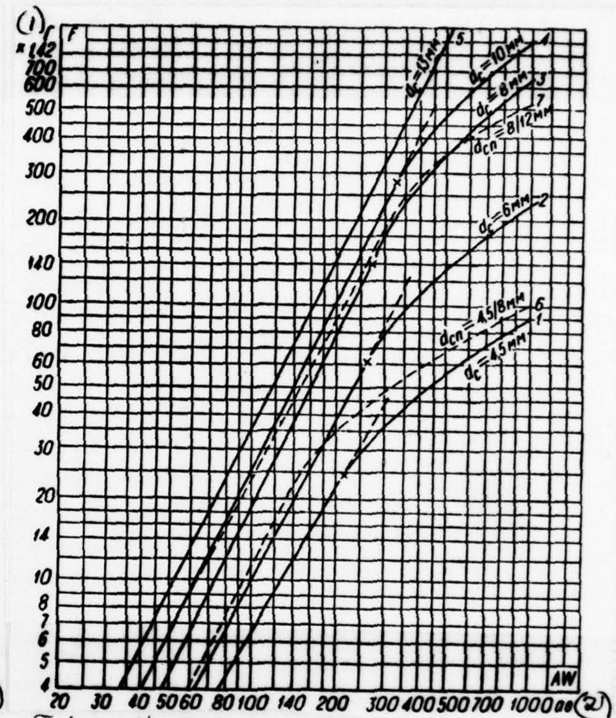

Fig. 4-31.

Fig. 4-30. Curves of the dependences of attracting force on the magnetizing ampere-turns with l = 35 mm and σ = 0.9 mm.

1 — d_c = 3 мм, 2 — d_c = 4,5 мм; 3 — d_c = 6 мм; 4 — d_c = 8 мм; 5 — d_c = 10 мм; 6 — d_c = 14 мм.

Key: (1). g. (2). AV.

Fig. 4-31. Curves of dependences of attracting force on magnetizing ampere-turns with l = 76 mm and σ = 0.9 mm.

1 — d_c = 4,5 мм; 2 — d_c = 6 мм; 3 — d_c = 8 мм; 4 — d_c = 10 мм; 5 — d_c = 13 мм; 6 — $d_{cп}$ = 4,5/8 мм; 7 — $d_{cп}$ = 8/12 мм

Key: (1) g; (2) AV.

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The length of the rectilinear calculated section of the full-load saturation curve of relay decreases with increase of working clearance and with decrease of the diameter of core.

ttab the diameter of the pole piece in practice barely affects the length of the straight portion of full-load saturation curve.

Thus, the application/use of the pole piece causes a decrease in the ampere-turns of function, other conditions being equal, but it does not increase the ultimate load of relay. On the contrary, the length of the straight portion of full-load saturation curve of relay with the pole piece a little decreases in comparison with the relay, which do not have the pole piece with the equal diameters of core and equal working air gaps.

Figures 4-32 gives the full-load saturation curves of the specimen/samples of the magnetic systems of the relays, which have the cores of identical diameter (8 mm), but different length (22, 35 and 76 mm) with σ = 0.9 mm.

From these characteristics it follows that with an increase in the length of core greatest design load of relay, other conditions being equal, decreases. Is explained this to the fact that with increase of the length of core the value of useful magnetic flux in working air gap decreases as a result of increase of leakage fluxes between the core and the body.

Analyzing the load characteristics of the specimen/samples of the magnetic systems cf relay (Figs. 4-26, 4-27 ..., 4-32), we see that the dependence of the attracting force of armature on magnetizing ampere-turns of all tested specimen/samples of relay on the calculated working section of each curve is virtually straight line in logarithmic scale. consequently, the calculated (working) section of the full-load saturation curve of relay can be approximated by the approximation formula:

$$F \approx F_{abl} \cdot AW^{a}, \quad (4-67)$$

where F_{abl} is the attracting force, which would have the relay in the magnetizing field, equal to one ampere-turn, if the initial section of characteristic was straight-line from value AW = 1 AV, and a - a slope tangent of the straight portion of full-load saturation curve to the axis of abscissas.

The values of quantity a of the specimen/samples of the magnetic systems cf relay with the cores of different size/dimensions it oscillates within small limits, approximately from 1.9 to 2.2.

For simplification in the conclusion/derivations, let us accept for all tested specimen/samples of relay value a equal to two (a = 2).

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In this case for determination graphically from Fig. 4-26, 4-27:, 4-32 values F_{abl} for each full-load saturation curve it is necessary through the middle rectilinear working section of this characteristic to draw straight line at an

angle 63°30' (a = 2) to the axis of abscissas and to prolong this direct/straight to its intersection with axis of ordinates, beginning with AW = 1 AV (for this purpose it is necessary to prolong down and to the left logarithmic grid on which are constructed full-load saturation curves). In connection with the fact that along the axis of the ordinates of full-load saturation curves for all tested specimen/samples of relay are deposit/postponed the values of the loads, applied to the long arm of bridge, it is necessary the values of quantities F to multiply by 1.42 (since the relation of the arms of bridge and of armature it is equal to 1.42).

The values of quantities $F_{\text{абл}}$, for all tested specimen/samples of the relays, obtained graphically, are given in table 4-4.

On by the datum of table 4-4 Na Ris. 4-33 are constructed dependence curves of values $F_{\text{абл}}$ from the value of clearance for all tested specimen/samples of relay.

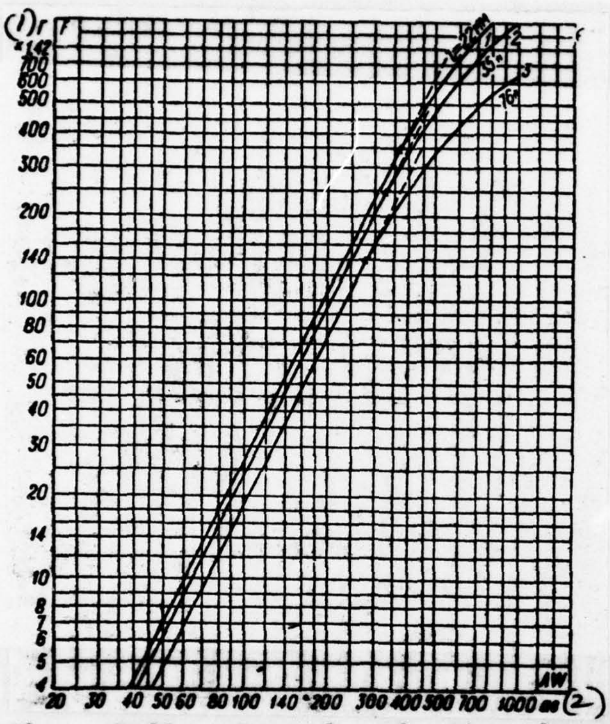

Fig. 4-32. Curved of the dependences of attracting force on the magnetizing ampere-turns with $d_c = 8$ mm and σ = 0.9 mm.

1 — l = 22 мм; 2 — l = 35 мм; 3 — l = 76 мм.

Key: (1). g. (2). AV.

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From the curves of Fig. 4-33, it follows that within the limits of changes of value σ from 0.3 to 1.2-1.5 mm

dependence curves of value F_{ab1} from σ in logarithmic scale for the different specimen/samples of relay in practice differ little from straight lines.

Therefore the dependence of value F_{ab1} from σ can be expressed by the approximation formula:

$$F_{ab1} \approx F_{e1}\sigma^{-b}, \quad (4\text{-}68)$$

where F_{e1} - a value of the attracting force F_{ab1} with σ = 1 mm and b - a slope tangent of straight line to the axis of abscissas.

The value of quantity b for the different specimen/samples of relay is within the limits approximately from 1.3 to 1.8.

For simplification in the conclusion/derivations, let us accept for all tested specimen/samples of relay value b, equal to 1.5 (b = 1.5), and let us conduct broken straight lines at an angle 56°20' through those curves for which b not is equal to 1.5.

Substituting in equation (4-67) instead of F_{ab1} its value from expression (4-68), we obtain for the attracting force of the armature of relay on the rectilinear working

sections of load characteristics, within the limits of value σ from 0.3 to 1.5 mm, the following approximation:

$$F \approx F_{\sigma 1} \sigma^{-b} A W^{a} \approx F_{\sigma 1} \sigma^{-1,5} A W^{2} = \frac{F_{\sigma 1} A W^{2}}{\sqrt{\sigma^{3}}}. \qquad (4\text{-}69)$$

Table 4-4. Value of quantities F_{ab_1} .

$d_{сп}$, мм		3	4,5	6	8	10	14	3/7	4.5/9	6/12
l, мм	a, мм	$F_{ab_1} \times 10^{-4}$ Г	$F_{ab_1} \times 10^{-4}$ Г	$F_{ab_1} \times 10^{-4}$ Г	$F_{ab_1} \times 10^{-4}$ Г	$F_{ab_1} \times 10^{-4}$ Г	$F_{ab_1} \times 10^{-4}$ Г	$F_{ab_1} \times 10^{-4}$ Г	$F_{ab_1} \times 10^{-4}$ Г	$F_{ab_1} \times 10^{-4}$ Г
22	0,3	41,2	75	160	204	202	256	97	160	170
	0,5	16,9	35	64	107	113	170	45	80	110
	0,7	9,7	20	36	56	68	114	30	50	70
	0,9	6,4	13,4	21	37	49	78	24	35	55
	1,2	4,2	8,5	15	20,6	31	49	16	20	35
	1,5	—	—	9,5	14,5	22	31	11,4	14	22
35	0,3	35,5	67	120	206	220	375	—	—	—
	0,5	13	31	53	90	116	180	—	—	—
	0,7	6,8	17,3	29	52	68	112	—	—	—
	0,9	3,9	11,4	21	35	46,5	75	—	—	—
	1,2	2,7	8,2	12,8	21,2	29	49,5	—	—	—
	1,5	—	5,4	7,8	—	20	34	—	—	—
						$d_{сп}$, мм	13	4,5/8	6/9	8/12
76	0,3	—	51	84	118	177	270	67	106	154
	0,5	—	24	40	55	83	130	37,6	51	72
	0,7	—	15	24	38	56,5	80	23,4	31	48
	0,9	—	10	15	26	37	53	18	21	34
	1,2	—	6	10,5	15	24,2	34	13,3	14	21
	1,5	—	—	7,5	—	17	—	—	—	—

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Thus, virtually when the saturation of steel of magnetic circuit is absent, and the constant value of the magnetizing ampere turns the attracting force of armature inversely proportional to the value of clearance to degree of 3/2 instead of 2 in formula (4-65).

Values $F_{э1}$ for the different specimen/samples of relay with b = 1.5, obtained from the curves of Fig. 4-33, are given in table 4-5. From table it follows that with an increase in the diameter of core and a decrease in its length value $F_{э1}$ grow/rises.

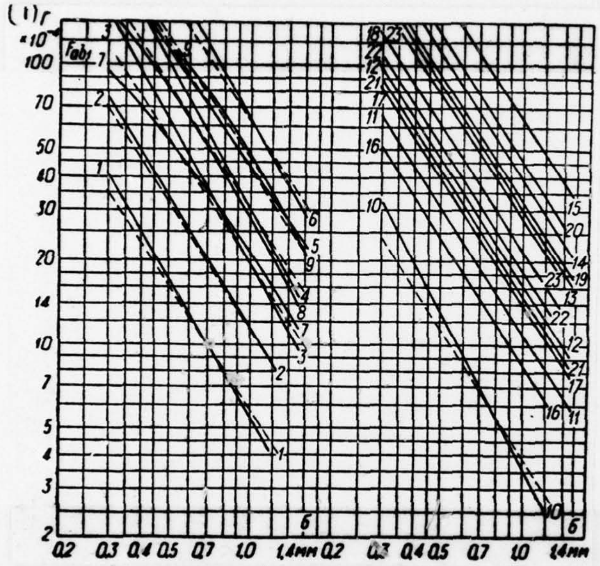

Fig. 4-33. Dependence curves of values F_{ab1} from the value of the clearance:

with $l = 22$ мм
1 — d_c = 3 мм; 2 — d_c = 4,5 мм; 3 — d_c = 6 мм; 4 — d_c = = 8 мм; 5 — d_c = 10 мм; 6 — d_c = 14 мм; 7 — $d_{сп}$ = 3/7 мм; 8 — $d_{сп}$ = 4,5/9 мм; 9 — $d_{сп}$ = 6/12 мм;

with $l = 35$ мм
10 — d_c = 3 мм; 11 — d_c = 4,5 мм; 12 — d_c = 6 мм; 13 — d_c = = 8 мм; 14 — d_c = 10 мм; 15 — d_c = 14 мм;

with $l = 76$ мм
16 — d_c = 4,5 мм; 17 — d_c = 6 мм; 18 — d_c = 8 мм; 19 — d_c = = 10 мм; 20 — d_c = 13 мм; 21 — $d_{сп}$ = 4,5/8 мм; 22 — $d_{сп}$ = = 6/9 мм; 23 — $d_{сп}$ = 8/12 мм.

Key: (1). g.

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AD-A066 134 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 9/1

CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)

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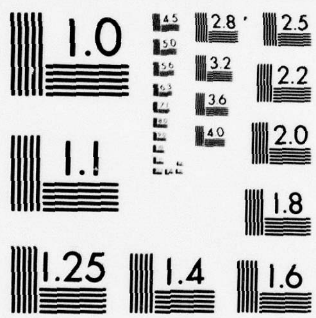

MICROCOPY RESOLUTION TEST CHART
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On by the datum of table 4-5 in Fig. 4-34 are constructed the curved 1, 2 and 3 dependences of value F_{s1} from the diameter of core at its different length (22, 35 and 76 mm), and also the curved 4, 5, 6 and 7 dependences F_{s1} on the diameter of the pole piece at the different length of cores, since at the presence of the pole piece value F_{s1} is determined not by the diameter of core, but by the diameter of the pole piece.

These curves (Fig. 4-34) within the limits of the value of the diameter of the pole piece (core) approximately from 4.5 to 14-19 mm are in logarithmic scale virtually direct/straight parallel lines and can be approximately approximated by the formula of the following form:

$$F_{s1} \approx F_{d1} d_{m}^{c}, \qquad (4\text{-}70)$$

where F_{d1} - the value of quantity F_{s1}, which would have relay with the diameter of positive cap, equal to 1 mm, if the initial section of curve was straight-line from value $d_m = 1$ mm, and c - a slope tangent of this straight line to the axis of abscissas.

Value c for the initial section of curve 1, the corresponding to change diameter of the pole piece (core) from 3 to 6 mm, is equal approximately 1.77 (c = 1.77), and for the section of this curve from 4.5 to 14 mm value c = 1.5. For the initial section of curve 2 rt 3.5 to 8 mm value c is also equal to 1.77, while for the section of this curve from 5 to 14 mm value c = 1.5. For a curve 5 value c is equal to 1.3 and for a curve 6 it is equal to 1.2.

For simplification in the conclusion/derivations, let us accept value c of constant for all curves and equal to 1.5 (c = 1.5) let us conduct in this case through the curves of Fig. 4-34 direct/straight dotted lines at an angle 56°20' whose tangent is equal to 1.5.

Table 4-5. Value of quantities

d_{cn} мм	l мм	F_{σ_1} Г	l мм	F_{σ_1} Г	l мм	F_{σ_1} Г
3	22	$5{,}7 \cdot 10^{-4}$	35	$3{,}9 \cdot 10^{-4}$	76	—
4,5		$11{,}5 \cdot 10^{-4}$		$10{,}7 \cdot 10^{-4}$		$8{,}8 \cdot 10^{-4}$
6		$19{,}5 \cdot 10^{-4}$		$16{,}2 \cdot 10^{-4}$		$14 \cdot 10^{-4}$
8		$30 \cdot 10^{-4}$		$28{,}5 \cdot 10^{-4}$		$21{,}5 \cdot 10^{-4}$
10		$42 \cdot 10^{-4}$		$39 \cdot 10^{-4}$		$31{,}5 \cdot 10^{-4}$
13		—		—		$45 \cdot 10^{-4}$
14		$69 \cdot 10^{-4}$		$63 \cdot 10^{-4}$		—
3/7		$21 \cdot 10^{-4}$	$d_{cn} = 4{,}5/8$ мм			$15 \cdot 10^{-4}$
4,5/9		$29 \cdot 10^{-4}$	$d_{cn} = 6/9$ мм			$18 \cdot 10^{-4}$
6/12		$45 \cdot 10^{-4}$	$d_{cn} = 8/12$ мм			$27 \cdot 10^{-4}$

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In this case from curved 1, 2 and 3 Fig. 4-34 we find the values of quantity F_{d1} for relay without the pole pieces: with l = 22 mm $F_{d1} = 1{,}33 \cdot 10^{-4}$ g (curve 1), with l = 35 mm $F_{d1} = 1{,}17 \cdot 10^{-4}$ g (curve 2) with l = 76 mm $F_{d1} =$ $0.95 \cdot 10^{-4}$G (curve 3).

For explaining the effect of dimensions (diameter) of the pole piece on the character of curves $F_{\sigma 1} = f(d_n)$ were determined also the values $F_{\sigma 1}$ for the second series of the specimen/samples of magnetic systems of valve type relays, having cores as diameter 9 mm with different pole pieces. These cores had length 25, 35 and 55 mm and diameter of pole pieces 9, 11, 13, 15, 17 and 19 mm.

The values of quantities $F_{\sigma 1}$ for the second series of the speci men/samples of the magnetic systems of relay are given in table 4-6.

According to the data of this table in Fig. 4-34 are constructed the curved 4, 5 and 6 (by dot-dash lines) dependences of value $F_{\sigma 1}$ from the diameter of the pole piece of relay at the length of cores 25, 35 and 55 mm.

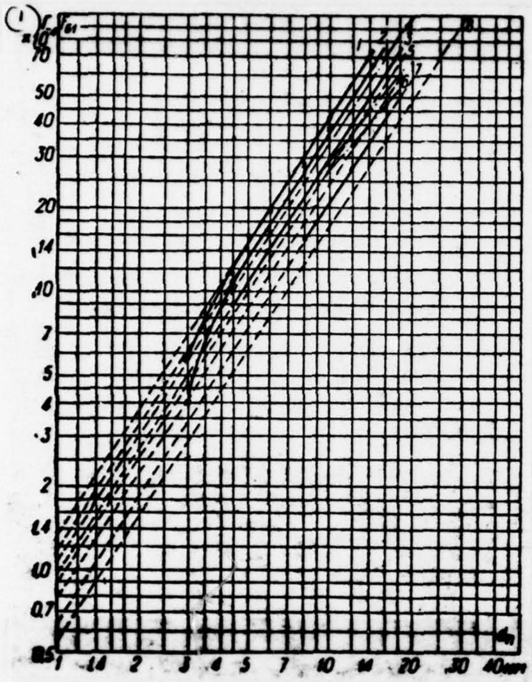

Fig. 4-34. Dependence of curves of value F_{e1} on the diameter of core (curves 1-3) and of diameter of pole piece (curves 4-8).

1 — l = 22 мм; 2 — l = 35 мм; 3 — l = 78 мм; 4 — l = 35 мм;
5 — l = 35 мм; 6 — l = 55 мм; 7 — l = 70 мм;
8 — l = 110 мм.

Key: (1). g.

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On curve 4 are deposit/postponed also the values F_{e1} for the cores of the first series by diameter 3/7, 4.5/9 and 6/12 mm by length 22 mm from table 4-6.

From Fig. 4-34 it follows that the curves 4, 5 and 6 are arrange/located below curves 1, 2 and 3; furthermore, the angle of the slope of curves 5 and 6 somewhat less (value c is equal to 1.2-1.3 instead of 1.5).

Consequently, in the presence of the pole piece specific attracting force F_{o1} is less than without the pole piece and with an increase in the diameter of pole piece and length of core (with a constant value of the diameter of core) slope angle on curves also is a little decreased.

It is necessary to consider that all conditions being equal the specific attracting force F_{o1} of valve type relay depends on construction, layout and relative size/dimensions of the cell/elements of magnetic circuit, value of ballast air gaps (joints of core with body and bodies with armature), the thicknesses of anticorrosive coatings and magnetic properties of steel of the magnetic circuit.

Table 4-6. Quantities of values F_{σ_1} (for the second series of cores).

$d_{сп}$, мм	l, мм	F_{σ_1}, г	l, мм	F_{σ_1}, г	l, мм	F_{σ_1}, г
9	25	$29\cdot10^{-4}$	35	$26{,}5\cdot10^{-4}$	55	$24\cdot10^{-4}$
9/11		$40\cdot10^{-4}$		$33\cdot10^{-4}$		$31\cdot10^{-4}$
9/13		$53\cdot10^{-4}$		$39\cdot10^{-4}$		$39\cdot10^{-4}$
9/15		$64\cdot10^{-4}$		$47\cdot10^{-4}$		$45\cdot10^{-4}$
9/17		$75\cdot10^{-4}$		$56\cdot10^{-4}$		$50\cdot10^{-4}$
9/19		$85\cdot10^{-4}$		$64\cdot10^{-4}$		$54\cdot10^{-4}$

Table 4-7. Values of quantities F_{σ_1} and F_{d_1}

(1) Тип реле	l, мм	$d_{сп}$, мм	$\sqrt{d_п^3}$	$F_{\sigma_1}\times10^{-4}$, г	$F_{d_1}\times10^{-4}$, г	(1) Тип реле	l, мм	$d_{сп}$, мм	$\sqrt{d_п^3}$	$F_{\sigma_1}\times10^{-4}$, г (2)	$F_{d_1}\times10^{-4}$, г (3)
РКН × 2	140	18/30	164	94	0,57	РКМ-1	55	7/11	36,5	31	0,85
КДР1	76	12	41,6	27,2	0,65	РКМП	54,5	9/14	52,4	45	0,86
HLR	77	9	27	23,5	0,87	(3) Макет	50	9	27	24	0,89
РПН	74	7,3/14,3	54,1	37	0,68	РС-13	40	7	18,5	22,5	1,21
РКН	70	9/15	58,1	39	0,67	РС-13	40	7/11	36,5	27	0,74
РКН	70	9	27	27,4	1,01	РМУ	32	8	22,6	28,5	1,26
						РСМ	15	5/8	22,6	22,5	0,99
(3) Макет	70	9/22,1	104	90,3	0,87	(3) Макет	13	9	27	34	1,26
600	64	6,3/11,2	37,5	29	0,78	РЭС10	11	3/4,5	9,54	12	1,26
РЭС14	60	7/15	58,1	43	0,74	РЭС15	8,5	1,9	2,62	4,9	1,86

Key: (1). Type of relay. (2). g. (3). Mock-up.

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Therefore at identical diameter and equal to the length of core the amount of specific attracting force F_{o1} of relay of the valve type of different constructions can oscillate within sufficiently wide limits (approximately from ±10o/c to ±30o/o).

Table 4-7 gives corrected values of value F_{o1} for 16 different types of valve relays by weight from 3 to 500 g and 3 mock-ups of magnetic systems.

The values of quantities F_{o1} a series of the relay of types RKN, RPN and RKN x 2 are deposit/postponed on Fig. 4-34 (curved 7 and 8). From curved 4, 5, 6 and 7 Fig. 4-34 we find the values of quantity F_{d1} at c = 1.5 for the relays with polar terminals, which have the length of core 22, 25, 35, 55, 76 and 140 mm. This of the value of quantity F_{d1} are given in table 4-8. Table 4-7 gives also values F_{d1} for the different types of the relays,

determined with the aid of formula (4-67) with c = 1.5.

For determination of the dependence of the attracting force of the armature of relay on the length of core of Fig. 4-35 are constructed dependence curves of value from the length of core for relay with polar F_{d1}

and without the pole piece. These curves within the limits of the length of core from 22 to 76 mm are in logarithmic scale virtually straight lines and can be expressed by the formula:

$$F_{d1} \approx F_{l1} l^{-k}, \qquad (4\text{-}71)$$

where F_{l1} - a value of attracting force F_{d1}, which would have relay with core length in 1 mm, if the initial section of curve was straight-line from value l = 1 mm, and k is a slope tangent of this straight line to the axis of abscissas.

Table 4-8. Values of quantities F_{d_1} and F_{l_1}

l, мм	F_{d_1}, Г (1)	$\sqrt[3]{l}$	F_{l_1}, Г (1)	(1A) Примечание
22	$1{,}33\cdot10^{-4}$	2,802	$3{,}73\cdot10^{-4}$	(2) Без полюсного наконечника
35	$1{,}17\cdot10^{-4}$	3,27	$3{,}83\cdot10^{-4}$	
76	$0{,}95\cdot10^{-4}$	4,24	$4{,}01\cdot10^{-4}$	
		(3) Среднее	$3{,}85\cdot10^{-4}$	
22	$1{,}07\cdot10^{-4}$	2,80	$3{,}0\cdot10^{-4}$	(4) С полюсным наконечником
25	$1{,}07\cdot10^{-4}$	2,92	$3{,}13\cdot10^{-4}$	
35	$0{,}88\cdot10^{-4}$	3,27	$2{,}88\cdot10^{-4}$	
55	$0{,}81\cdot10^{-4}$	3,80	$3{,}08\cdot10^{-4}$	
76	$0{,}67\cdot10^{-4}$	4,24	$2{,}83\cdot10^{-4}$	
140	$0{,}57\cdot10^{-4}$	5,19	$2{,}95\cdot10^{-4}$	
		(3) Среднее	$2{,}98\cdot10^{-4}$	

Key: (1) gf. (1A). Note. (2). Without the pole piece. (3). Average. (4). With the pole piece.

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Substituting in formula (4-69) instead of F_{l1} its value from expression (4-70) and instead of F_{d1} its value from equation (4-71), we will obtain for the attracting force of the armature of relay with unsaturated magnetic circuit the finally following approximation formula:

$$F \approx \frac{F_{d1} d_n^2 AW^2}{\delta^2} = \frac{F_{l1} AW^2 d_n^{1.5}}{\delta^{1.5} l^k} = \frac{F_{l1} AW^2 \sqrt{d_n^3}}{\sqrt{\delta^3}\cdot l^k}. \quad (4\text{-}72)$$

From Fig. 4-35 we find through curve 1 for the relay, which do not have pole piece, value F_{l1} and k: $F_{l1} = 3{,}1\cdot10^{-4}$

gf and k = 0.28.

For simplification in the conclusion/derivations, let us accept value k equal to 0.333; then according to dotted line 3 at this value of k, we find that $F_{\text{п}} = 3{,}85 \cdot 10^{-4}$ gf.

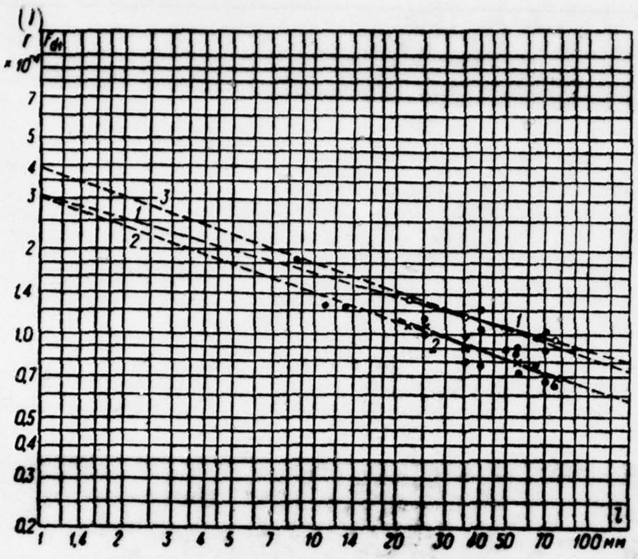

Fig. 4-35. Dependence curves of value F_{d1} from length of core. 1 - core without the pole piece (k = 0.28); 2 - core with the pole piece (k = 0.333); 3 - core without the pole piece (k = 0.333).

Key: (1). g.

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Substituting in equation (4-72) instead of F_{l1} and k of their value, we obtain for the attracting force of the armature of the relay, which does not have the pole piece:

$$F \approx 3{,}1\cdot 10^{-4}\frac{AW^2\sqrt{d_{\text{п}}^5}}{\sqrt{\sigma^5}\, l^{0{,}28}} \approx 3{,}85\cdot 10^{-4}\frac{AW^2\sqrt{d_c^5}}{\sqrt{\sigma^5}\sqrt[4]{l}}\ [\Gamma]^{(1)}, \quad (4\text{-}72a)$$

Key: (1). g.

where F is force in grams, $d_п$ - the diameter of the pole piece, equal to the diameter of core d_c in mm, size/dimensions l and σ in mm.

Ratio of the length of core to its diameter from the relay of assigned type different size/dimensions can be virtually considered constant value. Designating this sense through n, we find:

$$l = nd_c.$$

Substituting in equation (4-72) instead of l its value from last/latter expression, we obtain:

$$F \approx 3{,}85 \cdot 10^{-4} \frac{AW^2 d_c^{7/6}}{\sqrt{\sigma^3} \sqrt[3]{n}}. \quad (4\text{-}72б)$$

For the relay, which have core with the pole piece, with the aid of the curve of 2 Fig. 4-35 with k = 0.333 we find that $F_{l1} = 3 \cdot 10^{-4}$ g.

Substituting in equation (4-72) instead of F_{l1} and k of their value, we obtain for the attracting force of the armature of the relay, which has core with the pole piece:

$$F \approx 3 \cdot 10^{-4} \frac{AW^2 \sqrt{d_п^3}}{\sqrt{\sigma^3} \sqrt[3]{l}} = 3 \cdot 10^{-4} \frac{AW^2 d_п^{7/6}}{\sqrt{\sigma^3} \sqrt[3]{n}}. \quad (4\text{-}73)$$

Consequently, within limits indicated above of values $d_п$, l and σ the attracting force of the armature of relay at

the constant length of core is proportional to the diameter of the pole piece to degree of 3/2 instead of 2 and inversely proportional to the value of clearance also to degree of 3/2 instead of 2 in formula (4-65).

If the length of core varies in proportion to to its diameter, then the attracting force of the armature of relay will vary in proportion to to the diameter of the pole piece to degree of 7/6 (1.66).

If are assigned the values of load F and of the clearance σ, which correspond to the critical point of the electromechanical characteristic of relay, and are also known the diameter of the pole piece and the length of core, then the tentative value of the ampere-turns of the function of valve type relay (with error on the order of ± 10 ± 30o/o) can be determined with the aid of formulas (4-72a) and (4-73).

The tentative value of the ampere-turns of the function of valve type relay, which does not have the pole piece, will be equal

$$AW_c \sim \sqrt{\frac{F\sqrt{\sigma^3}\sqrt[3]{l}}{3{,}85\cdot 10^{-4}\sqrt{d_c^5}}} = 50{,}9\sqrt{\frac{F\sqrt{\sigma^3}\sqrt[3]{l}}{\sqrt{d_c^5}}}. \quad (4\text{-}74)$$

The ampere turns of the function of valve type relay, which has core with the pole piece, are tentatively equal to:

$$AW'_c \approx \sqrt{\frac{F\sqrt{\sigma^3 \sqrt[3]{l}}}{3\cdot 10^{-4}\sqrt{d_{п}^{3}}}} = 57{,}7\sqrt{\frac{F\sqrt{\sigma^3 \sqrt[3]{l}}}{\sqrt{d_{п}^{3}}}}. \qquad (4\text{-}75)$$

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These formulas are acceptable for precomputations within the limits of the straight portion of the full-load saturation curve of relay, for the valve type of the relays, which have the diameter of core (the pole piece) approximately from 3 to 18 mm and the length of core from 20 to 80 mm with the value of clearance from 0.3 to 1.2-1.5 mm.

Relay with the pulled armature.

For the derivation of the empirical formulas of the calculation of the attracting force of relay with the pulled armature, were used the full-load saturation curves of four electromagnets with diameters of armature (plunger) 125, 33.3 and 6 mm.

The air-gap diameter of the first electromagnet with conical end/lead (angle of taper 61°) was 125 mm, the length of coil 264 mm and the outside diameter of electromagnet 216 mm. Armature of the second electromagnet with flat/plane end/lead, its diameter 33.3 mm, the length of coil 88.9 mm and the outside diameter of coil 79.4 mm. The third electromagnet was the same basic dimensions as the second, but its armature had conical end/lead (angle of taper 60°). The fourth electromagnet had armature with flat/plane end/lead, air-gap diameter 6 mm, the length of coil 23 mm and its outside diameter 15 mm [1. 4-4].

As a result of the analysis of the full-load saturation curves of these four electromagnets, was derived the approximation formula for oriented calculation of the attracting force of electromagnets with the pulled armature with the unsaturated magnetic circuit:

$$F \approx 0{,}3 \cdot 10^{-4} d_a^2 \frac{AW^2}{\sqrt{\delta^3}} \overset{(1)}{[\Gamma]}. \qquad (4\text{-}76)$$

Key: (1). gf.

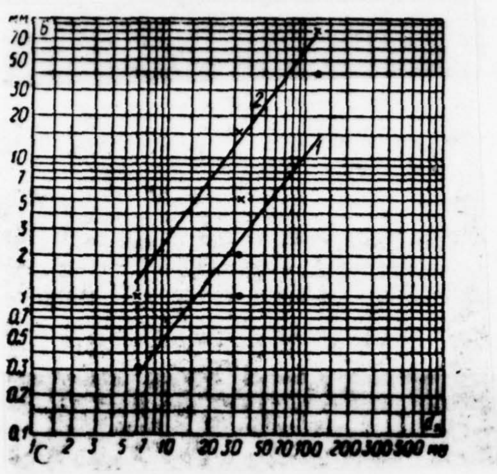

Fig. 4-36. Dependence curves of value of working air gaps from diameter of core between which curves $F_{ob1} = f(\sigma)$ are linear: 1 - upper limit of linearity; 2 - **lower limit** of linearity.

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This expression is tentative, since depending on the form of the end/lead of the armature, on the ratio of the length of coils to air-gap diameter, on relationship of the length of core and armature and on the size/dimensions of other cell/elements of magnetic circuit the full-load saturation curves of plunger electromagnets can change over wide limits.

Formula (4-76) can be used for the approximate computations of plunger electromagnets with air-gap diameter from 6 to 125 mm, which refer of the length of coil to air-gap diameter approximately from 2.1 to 2.7 (3.8) at the appropriate values of the quantities of working air gap (course of armature), the locating between curves limits of the linearity of dependence $F_{abl} = f(\sigma)$, those who were given in Fig. 4-36.

If are assigned air-gap diameter, the value of load and the course of armature, then the tentative value of the ampere-turns of the attraction of the armature of electromagnet can be determined from (4-76):

$$AW \approx \sqrt{\frac{F\sqrt{\sigma^3}}{0,3\cdot 10^{-4}\, d_{\pi}^2}} = 183\,\frac{\sqrt{F\sqrt{\sigma^3}}}{d_{\pi}}. \qquad (4\text{-}77)$$

b) The determination of greatest design load of the armature of relay.

Formulas (4-72), (4-73), (4-74), (4-75), (4-76) and (4-77) are used for determining the attracting force of armature and ampere-turns of function only on the straight portion of full-load saturation curve to the values of

attracting force, which do not exceed value $F = F_m$, at which begins to manifest itself the saturation of steel on any section of magnetic circuit (i.e. when greatest induction in steel it does not exceed 1.0-1.2 mT).

With a further increase in the magnetizing ampere-turns, the full-load saturation curve is bent, the attracting force of armature grow/rising 3-4 times. For providing sufficient speed of response and reliable work of relay, the attracting force must be 2-4 times more than greatest working load of armature with the datum of clearance. Therefore virtually greatest design load of armature with datum σ, which determines the ampere-turns of the function of relay, does not usually exceed value F_m, a of miniature/small relay to avoid a considerable increase of consumed power and greater overheating of winding design load of armature at the assigned clearance must be less F_m.

Consequently, for the calculation of the magnetic circuit of relay it is necessary to know the dependence F_m on the size/dimensions of core and length of working air gap.

Valve type relay.

For determining this dependence, we will use the full-load saturation curves specimen/samples examined above of 23 of the magnetic systems of valve type relay with the cores of different size/dimensions (part of these characteristics it is given in Fig. 4-26, 4-27..., 4-32).

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The values of quantities F_m for all tested specimen/samples of relay at the different size/dimensions of the clearance, obtained from the appropriate full-load saturation curves, are given in table 4-9. On by the datum of table 4-9 in Fig. 4-37 are constructed the curves of the dependences of greatest design load F_m on the value of working air gap σ for all tested specimen/samples of relay.

From the curves of Fig. 4-37, it follows that within the limits of changes of value σ from 0.3 to 1.2-1.5 mm the dependence of value F_m from σ in logarithmic scale for different specimen/samples in practice differs little from straight line and can be expressed by the approximation

formula:

$$F_m \approx F_{m\sigma 1}\sigma^{-\alpha}, \quad (4\text{-}78)$$

where $F_{m\sigma 1}$ - a value of the greatest attracting force F_m with σ = 1 mm and α - a slope tangent of straight line to the axis of abscissas.

Table 4-9. Values of quantities F_m

$d_{сп}$, мм		3	4,5	6	8	10	3/7	4,5/9	6/12
l, мм	σ, мм	F_m, Г (1)	F_m, Г (1)	F_m, Г (1)	F_m, Г (1)	F_m, Г (1)	F_m, Г (1)	F_m, Г (1)	F_m, Г (1)
22	0,3	47	200	500	1160	1700	24,2	100	215
	0,5	31	156	384	820	1500	18,5	71	170
	0,7	27	113	280	630	1180	15,6	60	140
	0,9	21,3	82	242	510	1030	14,2	53	123
	1,2	17,0	57	200	410	830	10,6	46	110
	1,5	—	—	170	340	690	—	42	—
35	0,3	42,6	145	400	690	1500	—	—	—
	0,5	27	99	270	560	1050	—	—	—
	0,7	20	85	220	430	820	—	—	—
	0,9	17	65	170	350	690	—	—	—
	1,2	13,4	55	140	290	560	—	—	—
	1,5	11,3	42,6	115	235	450	—	—	—
					$d_{сп}$,	мм	4,5/8	6/9	8/12
76	0,3	—	70	228	455	910	64	140	384
	0,5	—	50	142	313	660	50	105	256
	0,7	—	35,5	111	228	500	42,6	90	205
	0,9	—	28,4	92	199	380	35,4	78	175
	1,2	—	20	74	163	340	27	70	150
	1,5	—	—	64	—	280	—	—	—

Key: (1). gf.

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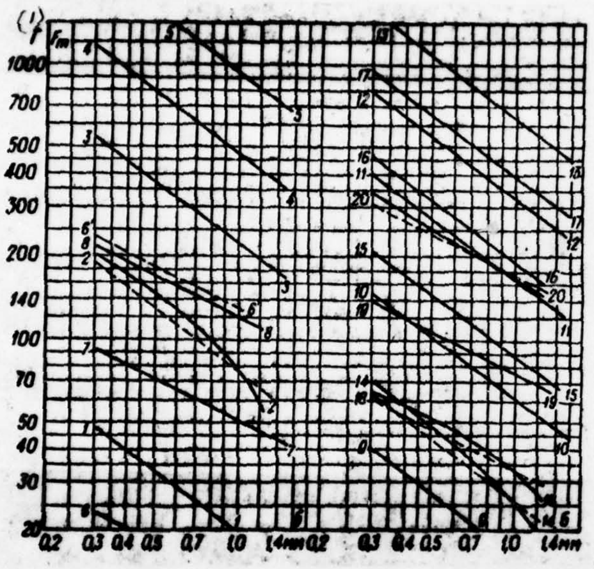

Fig. 4-37. Curved of dependences of greatest design load on value of clearance: with l = 22 mm;

1 — d_c = 3 мм; 2 — d_c = 4,5 мм; 3 — d_c = 6 мм; 4 — d_c = 8 мм; 5 — d_c = 10 мм; 6 — $d_{сп}$ = 3/7 мм; 7 — $d_{сп}$ = 4,5/9 мм; 8 — $d_{сп}$ = 6/12 мм;

with l = 35 mm

9 — d_c = 3 мм; 10 — d_c = 4,5 мм; 11 — d_c = 6 мм; 12 — d_c = 8 мм; 13 — d_c = 10 мм;

with l = 76 mm

14 — d_c = 4,5 мм; 15 — d_c = 6 мм; 16 — d_c = 8 мм; 17 — d_c = 10 мм; 18 — $d_{сп}$ = 4,5/8 мм; 19 — $d_{сп}$ = 6/9 мм; 20 — $d_{сп}$ = 8/12 мм.

Key: (1). gf.

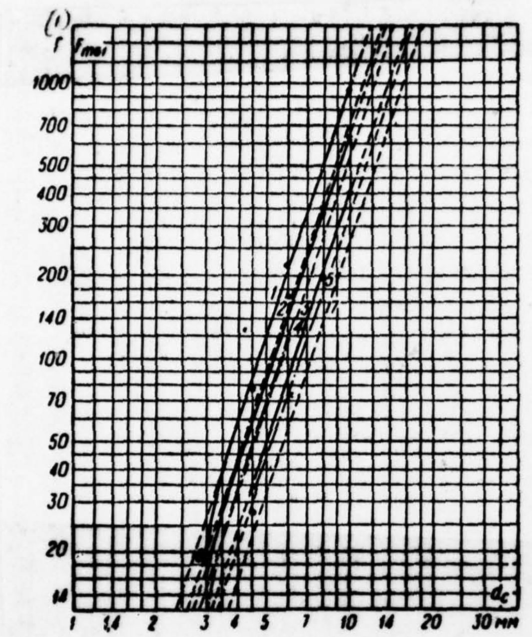

Fig. 4-38. Dependence curves of values $F_{\sigma m1}$ from diameter of core: core without pole piece. 1 - l = 22 mm; 2 - l = 35 mm; 3 - l = 76 mm; core with pole piece 4 - l = 22 mm; 5 - l = 76 mm; 6 - 11 mm; 7 - l = 140 mm.

Key: (1). g.

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The value of quantity α for the different specimen/samples of the relays, which do not have the pole

piece, varies within small limits and can be accepted equal to 0.75 (α = 0.75). For relay with the pole pieces value α can be taken as equal to 0.5 (α = 0.5).

Values $F_{m\sigma 1}$ for the different shapes of the relays, obtained from the curves of Fig. 4-37, are given in table 4-10. On by the datum of table 4-10 in Fig. 4-38 are constructed the curves of dependence value $F_{m\sigma 1}$ from the diameter of the core of relay at its different length 22, 35 and 76 mm). (Curved 1, 2 and 3 - for the specimen/samples of the relays, which do not have the pole piece, and dot-dash curves 4 and 5 - for the specimen/samples of relay with pole pieces). Curves 1 and 4 are related to cores by length 22 mm, curved 2 - to cores by length 35 mm and curved 3 and 5 - to cores by length 76 mm.

From Fig. 4-38 it follows that these curves within the limits of the value of the diameter of core approximately from 3 to 10 mm in logarithmic scale in practice differ little from straight lines and can be approximated by the approximation formula of the following form:

$$F_{m\sigma 1} \approx F_{md1} d_c^2, \qquad (4\text{-}79)$$

where F_{md1} - a value of the greatest attracting force $F_{m\sigma 1}$,

which would have relay with core diameter in 1 mm, if the initial section of curve was straight-line from value $d_c = 1$ mm, and β - a slope tangent of straight line to the axis of abscissas.

For a comparison in the figure, are plotted the values of quantities $F_{m\sigma 1}$ for a relay of the type R3S10, which has core as diameter 3/4.5 mm, and the mock-up of relay RKN, increased two times (RKN x 2), with the diameter of core 18/30 mm. Through these points are carried out broken straight lines 6 and 7, to parallel lines 1, 2, 3 and 4.

Table 4-10. Values of quantities. $F_{m\sigma_1}$

d_{cn}, мм	l, мм	$F_{m\sigma_1}$, г (1)	l, мм	$F_{m\sigma_1}$, г (1)	l, мм	$F_{m\sigma_1}$, г (1)	a
3	22	19,8	35	15,8	76	26,5	0,75
4,5		78		60		86	0,75
6		220		165		195	0,75
8		480		330		390	0,75
10		940		630	—	—	0,75
3,7		13	$d_{cn} = 4{,}5/8$ мм		76	33	0,5
4,5/9		50	$d_{cn} = 6/9$ мм		76	74	0,5
6/12		120	$d_{cn} = 8/12$ мм		76	175	0,5
3/4,5	11	19,5	$d_{cn} = 18/30$ мм		140	1600	0,5

Key: (1). g.

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Value β for the initial section of curve 1, the corresponding to change diameter of core from 2 to 4 mm, is equal approximately to four (β = 4), and for a section by this curve from 4 to 10 mm value β = 3. For the initial sections of curves 1 and 2 is from 3 to 6 mm value β = 3.24, while for the section of curve 2 - from 6 to 10 mm β = 2.75.

For simplification in the further conclusion/derivations, let us accept value β of constant for all curves and equal to three (β = 3) within the limits of changes in the diameter of core from 3 to 10 mm; then

$$F_{mo1} \approx F_{md1} d_o^3. \qquad (4\text{-}79a)$$

After continuing direct/straight 1, 2, 3, 4, 5, 6 and 7 Fig. 4-38 down before their intersection with the axis of ordinates, let us find the average values of quantity F_{md1} for the cores of different length. These values F_{md1} are

given in table 4-11 and are deposit/postponed on Fig. 4-39 depending on the length of core.

From Fig. 4-39 it follows that within the limits of changes of the length of the core of relay approximately from 20 to 80 mm (for relay with the pole pieces - from 10 to 140 mm) the curves of the dependences F_{md1} on l in logarithmic scale differ little from straight lines and can be expressed by the approximation formula:

$$F_{md1} \approx F_{m11} d_c^{\gamma}, \qquad (4\text{-}80)$$

where F_{m11} - a value of the greatest attracting force F_{md1}, which would have relay with core length in 1 mm, if the initial section of curve it was straight-line from value l = 1 mm, and γ - a slope tangent of straight line to the axis of abscissas.

Table 4-11 Magnitudes of values F_{md_1} and F_{ml_1}

l, мм	γ	$\sqrt[4]{l^3}$	$\sqrt{l}$	F_{md_1}, г (1)	F_{ml_1}, г (1)	Примечание (1A)
22	0,75	10,16	—	0,96	9,75	(2) Без полюсного наконечника
35	0,75	14,37	—	0,65	9,35	
76	0,75	25,7	—	0,39	10,0	
				(3) Среднее	9,71	
11	0,5	—	3,32	0,72	2,38	(4) С полюсным наконечником
22	0,5	—	4,69	0,54	2,53	
76	0,5	—	8,72	0,34	2,97	
140	0,5	—	11,83	0,27	3,19	
				(3) Среднее	2,77	

Key: (1). g. (1A). Note. (2). Without the pole piece. (3). Average. (4). With the pole piece.

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Substituting in equations (4-78) and (4-79) instead of values F_{me1} and F_{md1} of their value, we obtain approximate formula for determining the maximum value of the calculated attracting force of valve type relay:

$$F_m \approx \frac{F_{md1} d_c^{\beta}}{\sigma^{\alpha}} = \frac{F_{ml1} d_c^{\beta}}{\sigma^{\alpha} l^{\gamma}}. \qquad (4\text{-}81)$$

From Fig. 4-39 we find the value of quantity γ for the relay, which do not have the pole piece (curved 1), equal to 0.724, and for relay with the pole pieces (curved 2), equal to 0.385.

For simplification in calculated formulas, let us accept value γ for the relay, which do not have the pole piece, equal to 0.75 (γ = 0.75) and for relay with the pole pieces - equal to 0.5 (γ = 0.5).

The point of intersection of the broken direct 3 dependences of value F_{md1} from l at γ = 0.75 with the axis of ordinates in Fig. 4-39 gives to us the value of quantity F_{mn} for valve type relays, which do not have the pole piece, $F_{mn} = 9.7$ gf, while the point of intersection of straight line 4 (with γ = 0.5) with the axis of ordinates gives value F_{mn} for relay with the pole pieces $F_{mn} = 2.8$ gf. The values of quantities F_{mn} for some specimen/samples of the relays, determined with the aid of formula (4-80), are given in table 4-11.

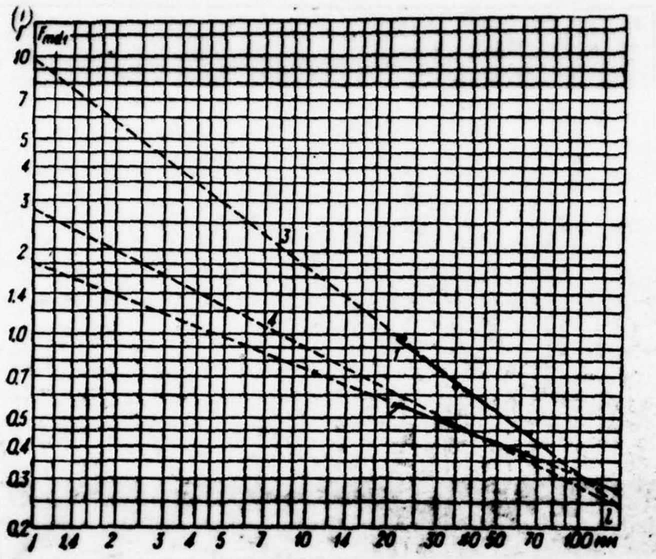

Fig. 4-39. Dependence curves of values F_{mdi} from length of core. 1 - core without the pole piece (γ = 0.724); 2 - core with the pole piece (γ = 0.385); 3 - core without the pole piece (γ = 0.75); 4 - core with the pole piece (γ = 0.5).

Key: (1). g.

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Consequently, the maximum value of the calculated attracting force of the armature of the relays, which do

not have the pole piece, will be equal to:

$$F_m \approx \frac{9{,}7 \cdot d_c^3}{\sqrt[4]{\sigma^3 l^3}}, \tag{4-82}$$

a for the relay, which have core with the pole piece,

$$F'_m \approx \frac{2{,}8 \cdot d_c^3}{\sqrt{\sigma}\sqrt{l}} = \frac{2{,}8 \cdot d_c^3}{\sqrt{\sigma l}}. \tag{4-83}$$

Here F_m is force in gf, size/dimensions d_c, σ and l - in mm.

These formulas give sufficient accuracy within the limits of changes in the diameter of core approximately from 3 to 18 mm, the lengths of core - from 20 (10) to 80 (140) mm and the values of working air gap from 0.3 to 1.2-1.5 mm.

Relay with the pulled armature.

In a similar manner with the aid of full-load saturation curves mentioned above of four electromagnets with the pulled armature is derived empirical formula for determining the maximum value of the calculated attracting force of plunger electromagnet:

$$F_m \sim 1{,}2\frac{d_n^{2,85}}{\sqrt{\sigma}} \sim 0{,}8\frac{d_n^3}{\sqrt{\sigma}}. \tag{4-84}$$

This formula is tentative and it is used within the

limits of a change in the air-gap diameter from 6 to 125 mm for the electromagnets with the pulled armature, which refer of the length of coil to air-gap diameter approximately from 2.1 to 2.7 (3.8) at the appropriate values of the quantities of working air gap, which are located between curves 1 and 2, given in Fig. 4-36.

4-11. Greatest and conditional work of electromagnet.

The mechanical work, completed by electromagnet during armature travel, is equal to:

$$A = \int_{\delta=\delta_1}^{\delta=0} F_э \, d\delta. \qquad (4\text{-}85)$$

In the particular case when the value of working clearance is low in comparison with the area of pole and magnetic circuit is not saturated, it is possible to substitute for $F_э$ its value from expression (4-62a); we have:

$$A = \int_{\delta_1}^{0} \frac{AW^2}{2\mu_0 S (R_м + R_\delta)^2} d\delta = \int_{\delta_1}^{0} \frac{AW^2}{2\mu_0 S R_м^2 \left(1 + \frac{\delta}{S\mu_0 R_м}\right)^2} d\delta. \qquad (4\text{-}86)$$

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Let us designate relation R_δ to $R_м$ by a:

$$a = \frac{R_\delta}{R_м} = \frac{\delta}{\mu_0 S R_м}.$$

then $\delta = R_{\text{п}} S \mu_0 a = ba$ and $d\delta = R_{\text{п}} S \mu_0 da.$

Passing to new variable, we obtain:

$$A = \int\limits_{ba_1}^{0} \frac{AW^2 R_{\text{п}} S \mu_0}{2\mu_0 S R_{\text{п}}^2 (1+a)^2} da = \frac{AW^2}{2R_{\text{п}}} \int\limits_{ba_1}^{0} \frac{da}{(1+a)^2} = \frac{AW^2}{2R_{\text{п}}} \cdot \frac{a_1}{(1+a_1)} \quad (4\text{-}87)$$

or

$$A = \frac{AW^2}{2R_{\text{п}}} \cdot \frac{R_{\delta}}{R_{\text{п}}\left(1+\frac{R_{\delta}}{R_{\text{п}}}\right)} = \frac{AW^2 R_{\delta}}{2R_{\text{п}}(R_{\text{п}}+R_{\delta})}. \quad (4\text{-}87\text{a})$$

From expression (4-87) it follows that with an increase in relation a the work increases and within limit it will be equal to:

$$A_m = \frac{AW^2}{2R_{\text{п}}} \overset{(1)}{[\text{нм}]} = \frac{2\pi AW^2}{981 \cdot R_{\text{п}} \cdot 10^6} = 6{,}4 \cdot 10^{-9} \frac{AW^2}{R_{\text{п}}} \overset{(2)}{[\text{кГ} \cdot \text{см}]}. \quad (4\text{-}88)$$

Key: (1). nm. (2). kg•cm.

Consequently, A_m is the greatest work which it can produce electromagnet with these ampere turns. This work on Fig. 4-40 is determined by the area, limited by static thrust (electromechanical) characteristic and the coordinate axes.

The value of the greatest work of electromagnet at the assigned ampere-turns depends exclusively on the reluctance of relay with the pullled armature $R_{\text{п}}$.

For the best use of a work, produced by electromagnet,

mechanical load line (controlling force) must coincide with thrust characteristics.

However, the virtually mechanical characteristic of relay is the largely broken line, which consists of several straight portions.

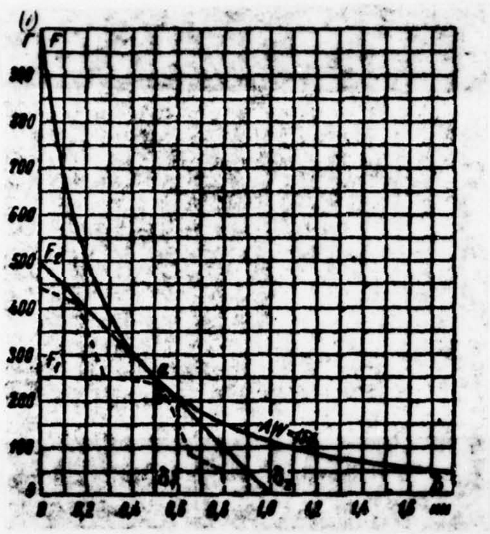

Fig. 4-40. Curved for determining work of electromagnet.

Key: (1). g.

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The mechanical characteristic of relay of the type RKN, loaded four by stud switches, is shown in Fig. 4-40 by dotted line.

So that the armature of relay would be pulled, it is necessary that in all way of its displacement/movement mechanical load would be less than the attracting force.

Therefore the mechanical characteristic of relay usually concerns electromechanical at one pcint b (critical point), and the area, limited by mechanical characteristic and the coordinate axes, always less than the area, limited by the thrust characteristics of relay and by these axes.

Let us examine two special cases mechanical characteristics of relay, depicted in Fig. 4-40:

1) mechanical characteristic with the constant load of armature (value of the load of armature does not change during its displacement/movement) - line F_1a and

2) mechanical characteristic with ampere-conductors per inch (value of the load of armature increases during its displacement/movement according to the law of straight line) - line $F_2a\delta_2$.

a) the load of armature is constant.

The work, necessary for the overcoming of the mechanical load of armature (controlling fcrce) with a constant value of this lcad F_1, is usually called conditional work and is expressed by the following formula:

$$A_1 = F_1\delta_1. \quad (4\text{-}89)$$

Graphically this work is determined by the area of rectangle $F_1 a \delta_1 0$. After substituting into expression for A_1 instead of F_1 its value from equation (4-62a) and after replacing value f with its value from formula (4-23), we will obtain:

$$A_1 = \frac{(Iw)^2 (R_0 gl + 2)^2 \delta_1}{2\mu_0 S^4 [l(R_{\text{м}} + R_0 R_{\text{в}} g) + q(R_{\text{в}} + R_0)]^2} = \Gamma \frac{\delta_1}{(B + DR_\delta)^2} = \frac{\Gamma \delta_1}{\left(B + D\frac{\delta_1}{\mu_0 S}\right)^2},$$

where

$$\Gamma = \frac{(Iw)^2 (R_0 gl + 2)^2}{8\mu_0 S}, \quad R_{\text{в}} = R_{\text{з}} + R_{\text{ст}} + R_{\text{ш}},$$
$$B = lR_{\text{м}} + qR_0 + (R_{\text{ст}} + R_{\text{ш}})(q + R_0 gl) \overset{(1)}{\text{и}} D = q + R_0 gl.$$

Key: (1). and.

For determining the condition by which the value of the conditional work of relay will be greatest, let us take derivative of A_1 on δ_1 let us equate it with zero; we will obtain:

$$\frac{dA_1}{d\delta_1} = \frac{\left(B + D\frac{\delta_1}{\mu_0 S}\right)^2 - \delta_1\left(\frac{2BD}{\mu_0 S} + \frac{2D^2}{\mu_0^2 S^2}\right)}{\left(B + D\frac{\delta_1}{\mu_0 S}\right)^4} = 0,$$

whence

$$B^2 - \frac{D^2 \delta_1^2}{\mu_0^2 S^2} = 0 \overset{(1)}{\text{и}} B = DR_\delta.$$

Key: (1). or.

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Substituting for B and D of their value, we will obtain:

$$R_\delta = \frac{lR_м + qR_0}{q + R_0 gl} + R_{ст} + R_ш. \qquad (4\text{-}90)$$

If we disregard the effect of leakage fluxes between core and housing of relay (g = 0), then condition for the maximum of the utilized conditional work of relay will take the following form:

$$R_\delta = lR_м + R_0 + R_{ст} + R_ш$$

or

$$R_\delta = R_п. \qquad (4\text{-}91)$$

Substituting in formula (4-89) extra-one hundred F_1 its value from (4-62a) and replacing value R_δ by equal to it value $R_п$, we obtain expression for the greatest value of the utilized conditional work of the relay:

$$A_{1m} = \frac{AW^2\delta}{2\mu_0 S(R_п + R_\delta)^2} = \frac{AW^2 R_\delta}{2(R_п + R_\delta)^2} = \frac{AW^2}{8R_п} \; [нм]^{(1)}$$

or

$$A_{1m} = 1{,}6\cdot 10^{-8}\frac{AW^2}{R_п} \; [кГ\cdot см]^{(2)}. \qquad (4\text{-}92)$$

Key: (1). nm. (2). kg•cm.

Consequently, the great value of the utilized conditional work (work with constant load) is 4 times lower

than the greatest work A_m (4-88), which it can produce this relay.

The reluctance of magnetic circuit depends on the value of induction in steel; therefore the value of the optimum course of the armature of relay and most advantageous area of the pole piece will change with the load of relay.

If value R_δ is not equal to $R_п$, then after dividing numerator and the denominator of equation (4-92) on $R_п^2$ and replacing relation R_δ to $R_п$ with a, we obtain for the conditional work of relay the following expression:

$$A_1 = \frac{AW^2 a}{2R_п (1+a)^2} = A_m \frac{a}{(1+a)^2}. \quad (4\text{-}93)$$

In Fig. 4-41 is constructed the curve of dependence relation A_1 to A_m from value a. From this curve it follows that during a change of the relation R_δ to $R_п$ within large limits - from 0.5 to 2 - the value of the utilized conditional work of relay decreases not more than by 11o/o.

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If we substitute into equation (4-92) instead of ampere-turns AW their value from expression (1-1), then we

will obtain:

$$A_{1m} = 1{,}6 \cdot 10^{-8} \frac{P}{CR_п} = 1{,}6 \cdot 10^{-8} \frac{P}{CR_\delta}. \qquad (4\text{-}92a)$$

Consequently, in the case of uniform flow distribution in working clearance, the absences of saturation stopped and neglect of the effect of leakage fluxes, the dependence of the value of the conditional work of relay from supplied power it must have linear character.

Heat conductivity for the heat flux, given up by the winding of relay into the environment,

$$G_т = \frac{P}{\theta}.$$

Electrical conductivity of the window of winding is equal to:

$$G_э = \frac{1}{C}.$$

Substituting in equation (4-92a) instead of P and C of their value from last/latter expressions, we will obtain [1. 4-12, 4-13]:

$$A_{1m} = 1{,}6 \cdot 10^{-8} \theta G_\delta G_э G_т \qquad (4\text{-}92б)$$

Consequently, efficiency of magnetic system is proportional to the temperature of the overheating of winding and to the product of three conductivities: magnetic, electrical and thermal.

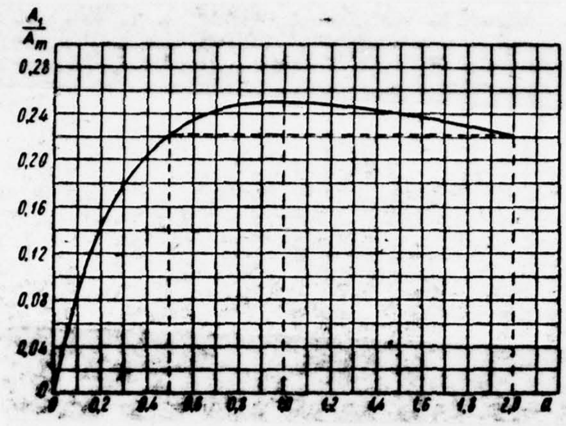

Fig. 4-41. Curved of dependence of relaticn A_1 to A_m on value a.

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Figures 4-42 gives experimental the curves of the dependences of conditional work on amount of the required power for seven relay of the valve type of different size/dimensions at the nominal values of the course of armature and plug of loosening. Fundamental these these relays are given in table 4-12. For the exception/elimination of the effect of the value of ratio l/d on the required power, the curves of the conditional work of the last/latter four types of relay were converted and given to value l/d = 7.8, but curved of the first

three types of relay - to value l/d = 3.2. The converted curves are constructed by dotted lines.

From the curves of Fig. 4-42, it follows that linear character have only initial sections of the curved first three types of relay.

Figures 1-26 shows the curves of the dependences of the conditional work of the different types of relay on the value of the course of armature at nominal sizes of the plugs of loosening and power 0.2 W. These curves have clearly expressed maximum, which corresponds to the optimum course of armature for each type of relay at power in the winding 0.2 W.

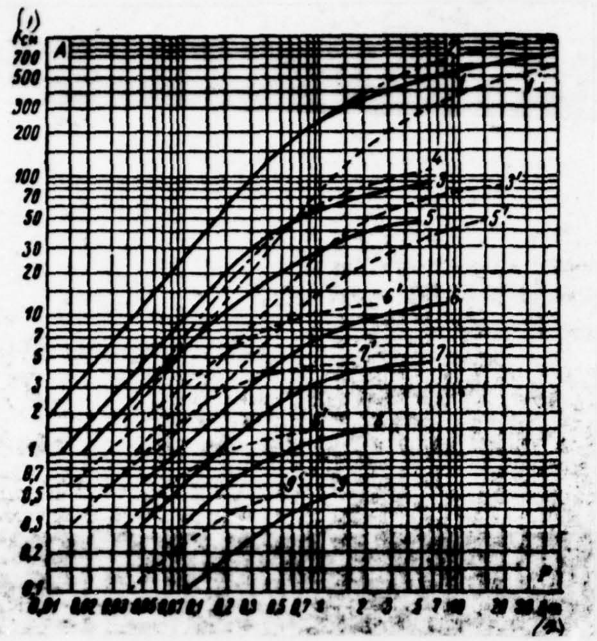

Fig. 4-42. Curve of dependence conditional work of relay from required power. 1 - mock-up of relay No 1 ($d_н = 30$ mm); 2 - mock-up of relay No 1 ($d_н = 18$ mm); 3 - relay of the type RKN ($d_н = 15$ mm); 4 - relay of the type RKN ($d_н = 9$ mm); 5 - relay of type rkm-1, 6 - relay of the type BSM; 7 - mock-up of relay No 2 (d = 3 mm); 8 - mock-up of relay No 3 (d = 2.4 mm); 9 - mock-up of relay No 4 (d = 2 mm).

Key: (1). Fuel and lubricants. (2). W.

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The curves of the dependence of power, consumed by valve type relay from their weight at the different values of conditional work, are given in Fig. 4-43.

Within the limits of the weight of relay from 100 to 3000 g and with light loads (to 5 g•cm) with l/d = 7.8 these curves can be approximated by the following approximation formula:

$$A_1 \approx 12{,}5P\sqrt[3]{Q}\ [\Gamma^{(1)}\cdot c\mathit{м}], \qquad (4\text{-}94)$$

Key: (1). g•cm.

where P is watts and Q - the weight of relay in grams.

Table 4-12. Fundamental these tested relays.

(1) Наименование реле	(2) Диаметр сердечника d, мм	(3) Диаметр полюса $d_п$, мм	(4) Длина сердечника l, мм	l/d	(5) $C \times 10^{-8}$, ом	(6) Ход якоря δ, мм	(7) Штифт отлипания δ_0, мм	(8) Вес реле Q, г
Макет реле № 1 (4)	18	30 (18)	140	7,8	1,7	1,6	0,6	2300
Реле типа РКН (10)	9	15 (9)	70	7,8	3,8	0,8	0,3	290
» » РКМ	7	11	55	7,9	5,1	1,1	0,1	112
» » РСМ	5	8	15	3,0	23,4	0,4	0,1	17
Макет реле № 2 (9)	3	5	10	3,3	39	0,45	0,05	6
» » № 3	2,4	3,8	7,5	3,1	40	0,4	0	3,1
» » № 4	2	3	6,5	3,2	46	0,4	0	1,8

Key: (1). Designation of relay. (2). Diameter of core d, mm. (3). Diameter of pole $d_п$, mm. (4). Length of core l, mm. (5). ohm. (6). Course of armature δ, of mm. (7). Plug of loosening δ_0, of mm. (8). Weight of relays Q, g. (9). Mock-up of relay. (10). Relays of the type.

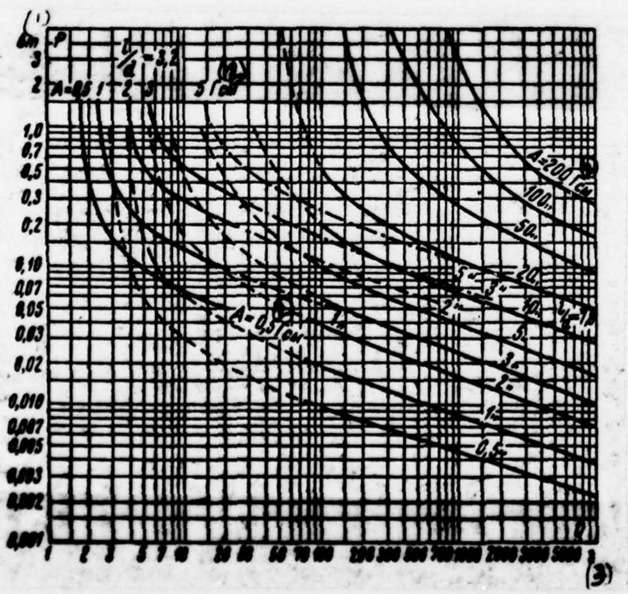

Fig. 4-43. Curved of dependence of power, consumed by relay from its weight at different values of conditional work.

Key: (1). W. (2). Fuel and lubricants. (3). g.

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b) the load of armature changes according to linear law.

In the case when the value of the mechanical load of armature changes according to the law of straight line, tangential to thrust characteristics at point a, work A_2, necessary for the overcoming of this charging, is determined by the area of right triangle $OF_2\delta_2$ (Fig. 4-40).

This work, obviously, is expressed by the following formula:

$$A_2 = \frac{F_2\delta_2}{2}. \qquad (4\text{-}95)$$

If $\delta_2 = 2\delta_1$, then of the similarity of triangles we find $F_2 = 2F_1$. Substituting in (4-95) instead of δ_2 and F_2 from value, we will obtain:

$$A_2 = 2F_1\delta_1, \qquad (4\text{-}95a)$$

i.e. with one and the same ampere-turns the work, utilized for the overcoming of the load of armature, which is

changed according to linear law, two times of the more work, necessary for the overcoming of the constant load of armature.

If we substitute into equation (4-95a) instead of F_1 its value from formula (4-62a), to differentiate expression for A_2 for δ_1 and to equate derivative with zero, then we will obtain the same solution as for the case of the constant load:

$$R_{\delta 1} = R_n \ \overset{(1)}{\text{или}} \ \frac{\delta_1}{\mu_0 S} = R_n.$$

Key: (1). or.

Substituting for δ_1 its value, we find the condition under which the work of relay will be greatest with ampere-conductors per inch:

$$R_{\delta 2} = \frac{\delta_2}{\mu_0 S} = 2R_n. \qquad (4\text{-}96)$$

The greatest **work, utilized for the over**coming of the mechanical load of armature under the linear law of the load **of the latter, will be equal to:**

$$A_{2m} = \frac{2AW^2}{8R_n} = \frac{AW^2}{4R_n}\ [\text{дж}] = 3{,}2\cdot 10^{-8}\frac{AW^2}{R_n}\ [\overset{(1)}{\text{кГ}}\cdot\text{см}]. \qquad (4\text{-}97)$$

Key: (1). kg•cm.

Consequently, with the load of armature, which is changed according to linear law, the greatest work,

necessary for the overcoming of this load, is equal to the half of the greatest work, produced by the armature of relay.

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4.12. Determination of the basic dimensions of the cell/elements of magnetic circuit.

a) the area of the pole piece.

For the calculation of magnetic circuit, it is necessary to know the value of mecharical load and the corresponding to it course of the armature of relay. If during armature travel load changes, then calculation one should conduct for the values of load and course, that correspond to the projecting points of mechanical characteristic.

These values can be considered assigned, since they can be determined from the mechanical characteristic of the contact system of relay.

For providing sufficient reliability of operation, it is necessary that the attracting force of the armature of relay with working coil current would be more than the nominal load of armature k_p once where k_p is a safety factor on attracting force.

The value of coefficient k_p usually is within the limits from 2 to 4. Therefore with the nominal load of armature F_n magnetic induction by steel of the magnetic circuit of relay must not exceed 1.0-1.2 mT (10000-12000 G).

The optimum value of area S_n in the assigned range of loads depends on the most economical value of magnetic induction in the saturated part of the magnetic circuit of relay.

Magnetic flux of heel (of framework) due to scattering in the absence of the pole piece is approximately 2-3 times more, but in the presence of the pole piece 1.2-1.6 times, it is more than in the working gap of relay. Therefore to avoid saturation, stopped magnetic circuits the

great value of induction in working gap B_r must not exceed 0.5-0.8 ml (5000-8000 G).

The most advantageous value of the area of the pole piece can be determined from condition (4-90) for the greatest conditional work of the relay:

$$R_\delta \approx \frac{\delta}{\mu_0 S_{\text{п}}} = \frac{lR_{\text{м}} + qR_{\text{э}}}{q + R_{\text{э}\delta} l} + R_{\text{ст}} + R_{\text{ш}},$$

whence

$$S_{\text{п.опт}} = \frac{\delta (q + R_{\text{э}\delta} l)}{\mu_0 [lR_{\text{м}} + qR_{\text{э}} + (R_{\text{ст}} + R_{\text{ш}})(q + R_{\text{э}\delta} l)]} \approx$$
$$\approx \frac{\delta}{\mu_0 (lR_{\text{м}} + R_{\text{э}} + R_{\text{ст}} + R_{\text{ш}})}. \quad (4\text{-}98)$$

In this formula enters the value of the specific resistor/resistance of steel $R_{\text{м}}$, therefore the solution it can be found by the method successive finding of with the aid of (4-24a) and (4-26).

Figures 4-44 gives experimental the curves of the dependences of the attracting force of relay of the type RKN on the diameter of the pole piece with different ampere-turns and the course of armature 0.8 mm.

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From these curves it follows that the most advantageous diameter of the pole piece decreases with an increase in

the ampere-turns of function.

For determining the optimum diameter of the pole piece of valve type, relay V. V. Vishniovskiy proposed the empirical formula, giving good results within limits from 200 to 600 ampere turns:

$$d_{п.опт} = [\delta(1 - 0{,}001 AW_{с}) + 0{,}85]\, d_{с}, \qquad (4\text{-}99)$$

where δ is a working air gap in mm, $d_{с}$ - the diameter of core in mm and $AW_{с}$ - the ampere-turns of the function of relay.

b) the diameter of core.

The nominal calculated value of the mechanical load of armature and the corresponding to it working air gap (course of armature) can be determined from the mechanical characteristic of relay. Therefore these values during the determination of the diameter of core can be considered assigned.

The most advantageous value of the diameter (section) of core can be determined when selecting of the optimum value of the area of the pole piece from condition for the greatest conditional work according to formula (4-98),

since the specific resistor/resistance of steel of magnetic circuit R_m depends on the section of core.

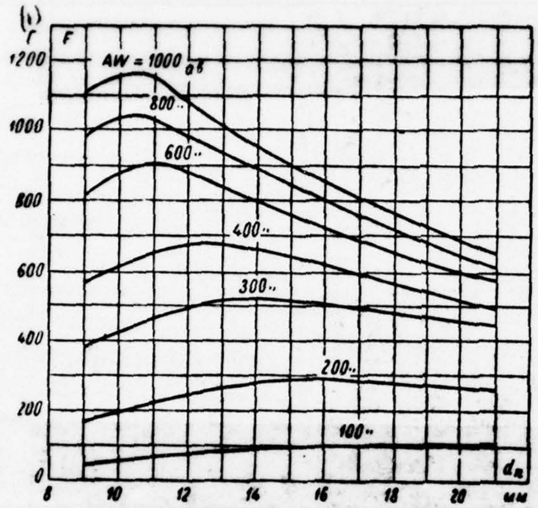

Fig. 4-44. Curved of dependences of attracting force of relay of type RKN on diameter of pole piece with different ampere turns and course of armature 0.8 mm.

Key: (1). g.

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However, this calculation method requires very much time; therefore for determining the tentative value of the diameter of the core of relay, we will use the approximation empirical formulas (4.82), (4.83) and (4.84).

Valve type relay without the pole piece.

From equation (4-82) for the greatest calculated attracting force we obtain the formula, which determines the tentative value of the diameter of the core of the relay, which does not have the pole piece:

$$d_c \approx \sqrt[3]{\frac{F_m \sqrt[4]{\sigma^3 l^3}}{9,7}} = 0,47 \sqrt[3]{F_m} \sqrt[4]{\sigma l}, \qquad (4\text{-}100)$$

where F_m - the nominal load of the armature of relay in g, σ - working air gap in mm, l and d_c - length and the diameter of core in mm.

The ratio of the length of core to its diameter of miniature/small relay oscillates usually within small limits approximately from 3.7 to 6, and of telephone relay - from 6 to 8.

Set/assuming the ratio of the length of core to its diameter for this type of relay by constant and designating this sense through n, we find:

$$l = nd_c. \qquad (4\text{-}101)$$

Substituting in equation (4-100) instead of l its value from last/latter expression, we obtain:

$$d_c \approx 0{,}47 \sqrt[3]{F_m} \sqrt[4]{\sigma n d_c},$$

whence we find the second formula for determining the diameter of the core of relay, which does not have the pole piece:

$$d_c \approx 0{,}36 \sqrt[3]{\sigma n \sqrt[3]{F_m^4}} = 0{,}36 F_m^{4/9} \sqrt[3]{\sigma n}, \qquad (4\text{-}100a)$$

where n is ratio of the length of core to its diameter.

Valve type relay with the pole piece.

In a similar manner from equation (4.38) we obtain formulas for determining the tentative value of the diameter of the core of relay, which has the pole piece:

$$d_0 \approx \sqrt[3]{\frac{F_m \sqrt{\sigma l}}{2,8}} = 0,71 \sqrt[3]{F_m \sqrt{\sigma l}} \qquad (4\text{-}102)$$

or

$$d_0 \approx 0,66 \sqrt[5]{F_m^2 \sigma n} = 0,66 (\sigma n)^{1/5} F_m^{2/5}. \qquad (4\text{-}102a)$$

In these formulas F_m - force in g, size/dimensions d_0, l and σ - in mm.

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Formulas (4.100) and (4.102) give sufficient for engineering calculations accuracy within the limits of changes in the diameter of core approximately from 3 to 18 mm, the lengths of core from 20(10) to 80(140) mm and the value of working air gap from 0.3 to 1.2-1.5 mm.

Relay with the pulled armature.

From equation (4.84) for the greatest calculated attracting force we find the formula, which determines the tentative value of the air-gap diameter (core) of relay with the pulled armature:

$$d_{n} \approx 1{,}08 \sqrt{F_m \sqrt{\sigma}}, \qquad (4\text{-}103)$$

where F_m - force in g, d_n and σ - in mm.

This formula is tentative and it is used within the limits of a change in the air-gap diameter from 6 to 125 mm for the electromagnets with the pulled armature, which refer of the length of coil to air-gap diameter approximately from 2.1 to 2.7 (3.8) at the appropriate values of the quantity of working air gap, which are located between curves 1 and 2 in Fig. 4.36.

(1)

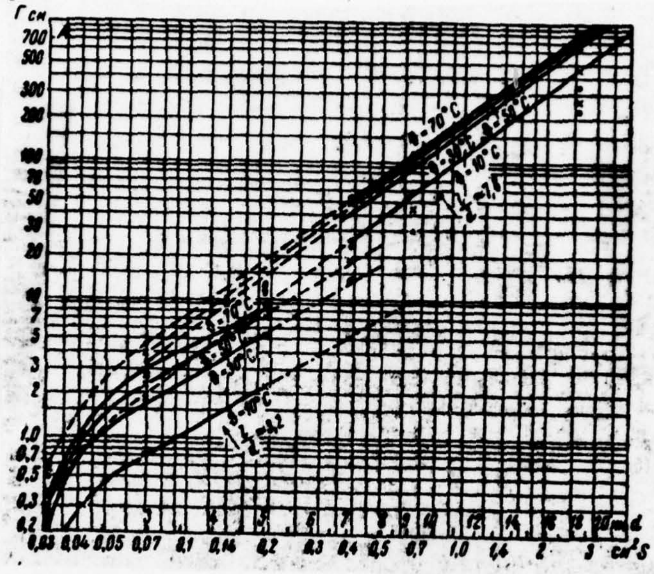

Fig. 4-45. Dependence of conditional work of electromagnet on section (diameter) of core at different temperatures of overheating of winding.

Key: (1) g cm.

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Figures 4-45 gives the curves of the dependences of the conditional work of valve type relay on the section (diameter) of core at the different temperatures of the overheating of winding and two values of the ratio of the length of core to its diameter.

These curves are constructed by author according to experimental materials for the open relay (without jacket).

When selecting of the diameter of core with the aid of these curves, it is necessary to proceed from working load of relay, which must be 2-4 times more than nominal.

The surface of the pole of relay is usually 2.5-4 times greater the section of core (diameter of the pole piece 1.6-2 times of the more diameter of core).

The advantageous relationship/ratio between the surface of pole and the section of core increases of proportionally to the value clearance and decreases with an increase of the load of relay (core induction). During large inductions application/use of the pole piece does not give necessary effect and, on the contrary, can lead to an increase in the ampere-turns of the function of relay (see Fig. 4-20).

When selecting of the size/dimensions of magnetic circuit, it is necessary to consider that an increase in the section of core and surface of pole gives an increase in triggering time and release/tempering of relay. Therefore high-speed relays must have a magnetic circuit of a small section without the pole piece.

Figures 4-46 gives curved magnetic flux distributions along the length of the core of relay of the type RKN with the pole piece and without it during clearances 0.1 and 0.9 mm even 200 ampere-turns.

From these curves it follows that for relay of the type RKN with σ = 0.9 mm and AW = 200 application/use of the pole piece gives an increase of the useful flow in clearance almost two times.

c) The length of core.

The length of core is determined in essence by the size/dimensions of the coils which depend on the sensitivity of relay and maximum permissible temperature excess of winding (at the continuous operation).

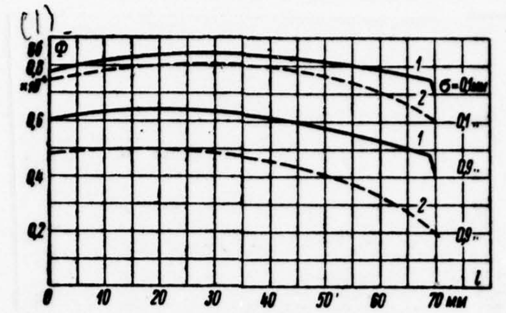

Fig. 4-46. Flow distribution along the length of core of relay of type RKN during AW = 200. 1 - with the pole piece; 2 - without the pole piece.
Key: (1) Wb.

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The most advantageous height/altitude of the winding of the relay of direct current does not usually exceed the diameter of core; therefore an increase in the cooling surface can be reached only because of the elongation of coil.

The length of core must be more than the length of winding to the thickness of the jaws of coil plus 1-5 mm (length of the projecting end/leads of core), i.e., on 2-10 mm.

Disregarding the heat removal through the jaws of coil and accepting the height/altitude of the winding of the equal to 0.7 diameters of core, we obtain for the cooling surface of the winding of relay the following expression:

$$S_{\text{к}} = \pi [D_0 + (D_0 + 2h)]\, l_{\text{к}} = \pi (2d_{\text{c}} + 1{,}4d_{\text{c}})\, l_{\text{к}} = 3{,}4\pi l_{\text{к}} d_{\text{c}}. \quad (4\text{-}104)$$

From formula (9.53a) for the relay, which does not have jacket, we find:

$$S_{\text{к}} = \sqrt{\frac{170^3 P_m^3}{\vartheta^3}},$$

where P_m - the highest efficiency, consumed by relay during continuous duty.

Substituting in equation (4.104) instead of $S_{\text{к}}$ its value from last/latter expression and solving equation relatively $l_{\text{к}}$, we obtain formula for determining the tentative value of the smallest length of the winding of the open relay:

$$l_{\text{нм}} \approx \frac{\sqrt{170^3 P_m^3}}{3{,}4\pi d_{\text{c}} \sqrt{\vartheta^3}} = \frac{207}{d_{\text{c}}} \sqrt{\frac{P_m^3}{\vartheta^3}} \ [\text{см}]. \quad (4\text{-}105)$$

If the temperature of the overheating of winding is equal to 70°C, then

$$l_{\text{нм}} \approx \frac{0{,}35}{d_{\text{c}}} \sqrt{P_m^3}.$$

The minimum length of the winding of the relay, protected by jacket, will be equal to:

$$l_{кж} \approx \frac{285}{d_c}\sqrt{\frac{P_m^2}{\vartheta^3}} = \frac{0{,}5}{d_c}\sqrt{P_m^2} \qquad (4\text{-}105a)$$

The ratio of the length of core to its diameter of normal and telephone relay usually is within the limits from 6 to 10.

With an increase in the length of core, decreases the value of useful flow in working clearance and increases triggering time and release/tempering of relay. Therefore for a high-speed relay and the electromagnets, working it is short-term (in pulsed operation), the ratio of the length of core to its diameter has considerably smaller value - from 3 to 6.

For normal and time-lag relay the application/use of short cores is not rational, since in this case they increase the diameter of coil and the average length of turn, increases the consumption of copper and decreases triggering time and release/tempering of relay.

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d) The most advantageous size/dimensions of coil.

According to formulas (1-1) and (4-72a) for the power, consumed by the winding of the relay, which does not have the pole piece, it is possible to write the following expression:

$$P = C \cdot AW^2 = \frac{\pi\rho \cdot 10^{-8} F \sqrt{\sigma^3} \sqrt[3]{l} \, (D_0 + h)}{3{,}85 \cdot 10^{-4} l k_3 h \sqrt{d_c^3}}. \qquad (4\text{-}106)$$

Consequently, at the constant values of the amount of the attracting force and working air gap (course of armature) the power, consumed by relay, inversely proportional to the diameter of pole core to degree to 3/2 and total cross sections of copper of winding (lhk_3), and directly proportional to the length of the mean turn of winding.

Outside diameter and the length of coil are limited to the overall dimensions of relay and therefore for this relay they are constant values.

The outside diameter of the winding of the relay

$$D = D_0 + 2h = a_1 d_c + 2h, \qquad (4\text{-}107)$$

where a_1 is the coefficient, which considers the thickness of the insulation between the core and the winding. Value

a_1 is within the limits from 1.05 to 1.15-1.2.

From last/latter equation we obtain expression for the height/altitude of the winding:

$$h = \frac{D - a_1 d_c}{2}. \qquad (4\text{-}107a)$$

Substituting in equation (4-106) instead of h and D_0 their values from last/latter expression, we obtain:

$$P = \frac{\pi\varphi F \sqrt{\sigma^3}\left(a_1 d_c + \frac{D - a_1 d_c}{2}\right)}{0{,}385 \sqrt[3]{\mu} \cdot k_з \sqrt{d_c^3}\left(\frac{D - a_1 d_c}{2}\right)} = \beta_1 \frac{D_1 + d_c}{(D_1 - d_c)\, d_c^{3/2}}, \qquad (4\text{-}108)$$

where $\beta_1 = \frac{\pi\varphi F \sqrt{\sigma^3}}{0{,}385 \sqrt[3]{\mu} \cdot k_з}$ and $D_1 = \frac{D}{a_1}$.

Let us introduce instead of the diameter of core d_c relative value d_c/D_1; then equation (4-108) can be rewritten in the following form:

$$P = \frac{\beta_1\left(1 + \frac{d_c}{D_1}\right)}{D_1^{3/2}\left(1 - \frac{d_c}{D_1}\right)\frac{d_c^{3/2}}{D_1^{3/2}}} \qquad (4\text{-}108a)$$

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From this equation it follows that if we increase the diameter of core, then within limit $d_c = D_1\,(h = 0)$ and the power, necessary for the function of relay, will approach infinity. If we, on the contrary, waist of core to zero (h = 0.5D), then the power of the function of relay will also approach infinity.

For determining the conditions under which the power, consumed by relay, will have small value, let us equate zero derivative of equation (4-108) for value d_c; we obtain:

$$\frac{dP}{d(d_c)} = \frac{(D_1 - d_c)\,d_c^{3/2} - (D_1 + d_c)\,[1{,}5\,(D_1 - d_c)\,d_c^{1/2} - d_c^{3/2}]}{[(D_1 - d_c)\,d_c^{3/2}]^2} = 0,$$

whence

$$(D_1 - d_c)\,d_c - 1{,}5\,(D_1^2 - d_c^2) + (D_1 + d_c)\,d_c = 0$$

or

$$1{,}5 d_c^2 + 2D_1 d_c - 1{,}5 D_1^2 = 0.$$

First solution to this equation gives the condition under which the power, consumed by the winding of relay, will have the minimum value:

$$d_c = \frac{-2D_1 \pm \sqrt{4D_1^2 + 4 \cdot 1{,}5^2 D_1^2}}{3} = 0{,}535 D_1 = \frac{0{,}535}{a_1} D. \quad (4\text{-}109)$$

(Second solution to equation with minus sign of physical sense does not have).

Substituting in (4-109) instead of D its value from equation (4-107), we find the advantageous relationship/ratio between the height/altitude of winding and the diameter of the core of the relay:

$$d_c = \frac{0,535}{a_1}(a_1 d_c + 2h),$$

whence

$$h = 0,435 a_1 d_c. \qquad (4\text{-}110)$$

If the value of coefficient a_1 is equal to 1.1, then h = 0.48 d_c.

After substituting in (4.108) instead of value D of its value from expression (4-109), we will obtain equation for a minimum power coefficient, consumed by the relay:

$$P_м = \beta_1 \frac{d_c + 0,535 d_c}{(d_c - 0,535 d_c)\, d_c^{3/2}} = \beta_1 \frac{3,3}{d_c^{3/2}}. \qquad (4\text{-}108б)$$

At the derivation of these formulas, the value of duty factor k_3 was accepted by constant, not depending on the diameter of core. However, virtually the value of duty factor decreases with an increase in the diameter of core. According to equation (4.107a) with an increase in the diameter of core decreases the height/altitude of winding, and if turn number must remain constant/invariable, then the diameter of wire and duty factor decrease.

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With an increase in the diameter of core of relay of the type RKN from 7 to 16 mm and with winding with 28,000 turns the wire diameter decreases from 0.12 to 0.08 mm.

The duty factor of the wire of the brand of P3L during a change in the diameter of wire from 0.08 to 0.12 mm can be expressed depending on the diameter of the core of relay of the type RKN by the following approximation formula:

$$k_3 \approx 0{,}85 \cdot d_c^{-0{,}2}.$$

In this case formula (4-108) will take the form

$$P \approx \beta_2 \frac{(D_1 + d_c)\, d_c^{0{,}2}}{(D_1 - d_c)\, d_c^{3/2}} = \beta_2 \frac{D_1 + d_c}{(D_1 - d_c)\, d_c^{1{,}3}}, \qquad (4\text{-}108\text{c})$$

and the advantageous relationship/ratio between the height/altitude of winding and the diameter of core will be equal

$$h \approx 0{,}52 a_1 d_c \approx 0{,}57 \cdot d_c. \qquad (4\text{-}111)$$

For relay with the pulled armature, the attracting force, according to formula (4-76), is proportional to the square of air-gap diameter (to section of armature).

In this case the most advantageous height/altitude of the winding

$$h \approx 0,306 a_1 d_я \approx 0,336 \cdot d_я. \quad (4\text{-}112)$$

If we consider assigned (constant) not outside diameter of winding, but the outside diameter of the screen of plunger relay, then the most advantageous height/altitude of winding will be equal [4-41]

$$h \approx 0,42 \cdot d_я. \quad (4\text{-}112a)$$

Figures 4-47 gives the curve of the dependence of the power, consumed by the winding of relay (in the relative units), on the ratio of the height/altitude of winding to the diameter of core, constructed according to formula (4-108).

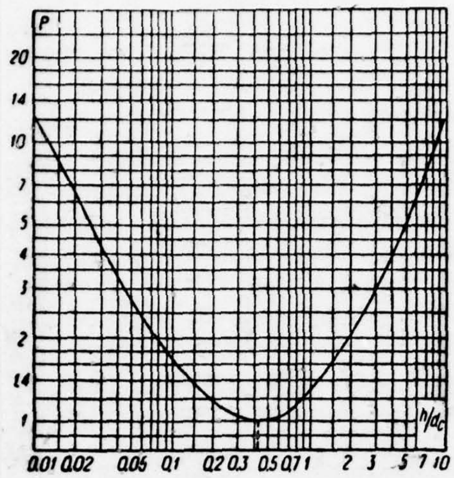

Fig. 4-47. Curved of dependence of power of function of relay on relation h/d_c with constant value D.

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From this curve it follows that during the deviation of the height/altitude of the winding of relay from the most advantageous value over wide limits: from $h_1 = 0{,}25 \cdot d_c$ up to $h_2 = 0{,}76 \cdot d_c$, the power, consumed by the winding of relay, it increases not more than by 10o/o. Therefore of miniature/small and miniature relay the ratio of the height/altitude of winding to the diameter of core usually is within the limits from 0.5 to 1.0, and of the relay of large overall sizes from 0.25 to 0.5.

With the assigned magnitude of the diameter of core and other equal conditions, the power, consumed by relay, decreases with an increase in altitude of winding, but in this case the overall size of relay increases because of an increase in the diameter of the ccil of relay.

Let us introduce into equation (4-106) instead of the height/altitude of winding h relative value h/d_c and replace D_0 on d_c; we will obtain:

$$P=\beta_1\frac{d_c+h}{\sqrt{d_c^3}\cdot h}=\frac{\beta_1}{\sqrt{d_c^3}}\cdot\frac{1+\frac{h}{d_c}}{\frac{h}{d_c}}. \qquad (4\text{-}106a)$$

Consequently, with increase in h power asymptotically approaches the limit, equal to $\beta_1/\sqrt{d_c^3}$.

Figures 4-48 gives the curve of the dependence of power (in the relative units), consumed by relay, on relation h/d_c with a constant value d_c.

From this curve evident that the relation h/d_c one ought not to take more than unit, since the required power in this case is little affected, but the consumption of copper rapidly increases.

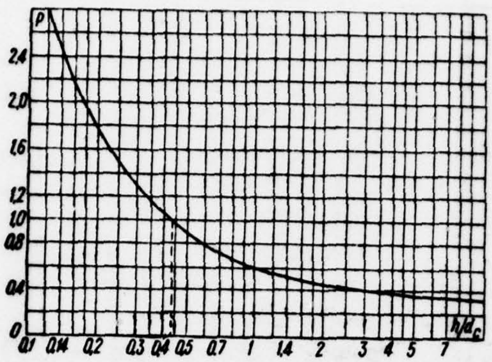

Fig. 4-48. Curved of dependence of power of function of relay on relation h/d_c with constant value d_c.

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e) The size/dimensions of housing, base and armature.

The section of housing and base (framework) of relay to avoid saturation must be not less than the section of the core:

$$S_к = S_0 \geqslant S_c. \quad (4\text{-}113)$$

The width of housing is determined by the construction of contact system and by a quantity of contact groups. For a decrease in the overall sizes of relay, the width of housing must not be more than the outside diameter of coil.

The thickness of housing $b_{к}$ depends on its width $a_{к}$ and it must be equal to:

$$b_{к}=\frac{S_{к}}{a_{к}}. \quad (4\text{-}114)$$

However, it is necessary to note that the thickness of housing must be sufficient for providing the necessary rigidity of construction and stability of the adjustment of relay. Base (framework) must be additionally checked to saturation in the site of joint with core.

Magnetic flux falls into the base through the lateral surface of the cylinder whose diameter is equal to the diameter of core d, and height/altitude - to thickness of base b_0.

To avoid the saturation of base in the place of the transition of flow, must occur the following inequality:

$$\pi d b_0 \geqslant \frac{\pi d^2}{4},$$

whence

$$b_0 \geqslant \frac{d}{4}. \quad (4\text{-}115)$$

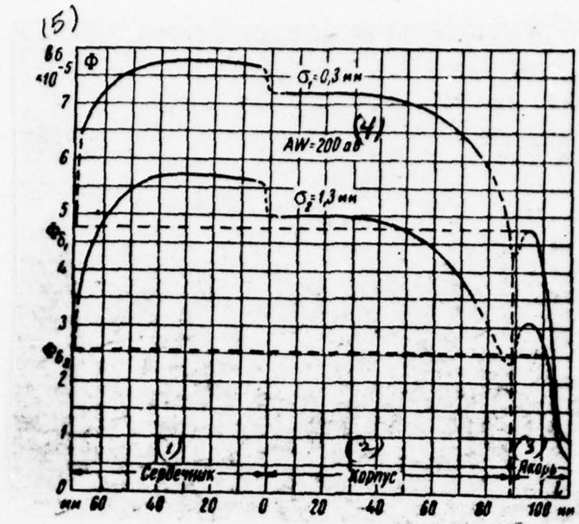

Fig. 4-49. Curved magnetic flux distributions along the length of magnetic circuit of relay of type RKN.

Key: (1). Core. (2). Housing. (3). Armature. (4). ampere-turns. (5). Wb.

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Figures 4-49 gives curved magnetic flux distributions along the length of the magnetic circuit of relays of the type RKN, constructed by V. V. Vishniovskiy.

The section of armature can be accepted less than the section of core, since induction of the end/lead of the

core is considerably less than in its base:

$$S_n \geqslant (0,6 \div 1,0) S_0. \quad (4\text{-}116)$$

All these relationship/ratios are especially tentative and therefore the basic dimensions of all cell/elements of the magnetic circuit of relay must be refined after verifying calculation. In this case, it is necessary to focus attention on that so that would be provided the reserve on attracting force not less twofold.

f) The course of armature.

Reluctance stopped magnetic circuits with light loads usually less than the resistor/resistance of clearance, and therefore for sensitization of relay was desirable the slow speed of armature. However, a decrease in the course is led to an increase in the gear ratio of armature, which complicates the construction of relay. Furthermore, relay with the slow speed of armature requires greater accuracy during production and possesses the smaller uniformity of the parameters.

Therefore relay usually have comparatively large course of armature (approximately from 0.4 to 1.5 mm) and only in

high-speed relays for an increase in speed of response the course of armature decreases to 0.25-0.4 mm. Polar relays have a course of armature 0.05-0.15 mm. The relays, intended for interrupting of high stresses and currents, must possess the large course of armature.

g) the distance between contacts.

The gear ratio of armature (relation of the arms of armature and bridge) with the assigned course depends on distance between contacts and the construction of contact system. In electromagnetic relays the distance between contacts usually is within the limits from 0.3 to 0.9 mm. Applied the gaps among the contacts of less 0.3 mm should not be that as a result of erosion is reduced the reliability of the operation of contact system.

Telegraph type high-speed relays with the special construction of contact system and special relays with platinum contacts, workers with light electrical loads, have considerably smaller distances between contacts - from 0.05 to 0.25 mm. Relays with silver contacts, the breaking stresses are above 100 V, they must have a distance among the contacts of more than 0.3 mm.

The dependence of the breakdown voltage between contacts from air-gap clearance is given in Fig. 18-7.

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4-13. Calculation of magnetic systems for minimum space and weight.

The overall dimensions of relay and its weight depend on the full load of armature with the assigned magnitude of working clearance, from the power, necessary for function, and also from the construction of the magnetic and contact systems of relay. With a decrease in the load of armature and working air gap and with an increase in the power of function overall dimensions and the weight of relay decrease.

However, with a decrease in the space of relay and an increase in the required power, grow/rises the temperature of the overheating of winding. Therefore the size decrease

of relay with the assigned load of armature is limited to the greatest permissible temperature of the wire insulation of winding.

The weight of relay is composed of the weight of steel of magnetic circuit, weight of copper of winding, weight of contact system and all remaining elements of the construction of relay.

The weight of contact system, base of the relay, jacket and other elements of its construction it is possible to consider proportional to the weight of active materials (they began magnetic circuits Q_c and coppers of winding $Q_м$); therefore the weight of the relay

$$Q \approx k_2 (Q_c + Q_м), \qquad (4\text{-}117)$$

where k_2 is a proportionality factor.

The weight of steel of magnetic circuit in grams tentatively can be expressed by the following formula

$$Q_c = sL\gamma_c k_4 \cdot 10^{-3} = \frac{\pi d_c^2}{4} L k_4 7{,}8 \cdot 10^{-3}, \qquad (4\text{-}118)$$

where s is a section of magnetic circuit in mm², L - the average length of magnetic circuit in mm, d_c - the diameter of core in mm, γ_c - density they stopped

($\gamma_c = 7{,}8$ g/cm^3), k_4 - the coefficient, considering the nonuniformity of the section of magnetic circuit over its length and the weight of the protruding (inactive) parts of the core, armature and housing.

The average length of steel of the magnetic circuit of the relay

$$L = 2l_c + 2l_я = 2l_c + 2k_5 l_c,$$

where l_c is length of core, $l_я$ - the length of the active part of the armature or base, which can be counted to the proportional length of core, and k_5 - proportionality factor.

Substituting in equation (4-118) instead of L its value from last/latter expression, we obtain:

$$Q_c = \frac{\pi d_c^2}{4} 2l_c (1 + k_5) k_4 7{,}8 \cdot 10^{-3} = 12{,}25 \cdot 10^{-3} k_4 (1 + k_5) l_c d_c^2. \quad (4\text{-}118a)$$

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The weight of copper of winding in grams, as is known, is expressed by formula (6-8):

$$Q_м = \pi l_к h (D_0 + h) \cdot 10^{-3} k_3 \gamma_м,$$

where D_0 - an inner diameter of the winding of relay (diameter of coil form) in mm, by h - a height/altitude cf winding in mm, $l_к$ - length of winding in mm, k_3 - a duty factor of winding space and $\gamma_м$ - density of copper ($\gamma_м = 8,9$ g/cm³).

Values D_0 and h can be considered proportional to the diameter of the core:

$$D_0 \approx a_1 d_c \quad и \quad h \approx a_2 d_c. \qquad (4\text{-}119)$$

The length of the winding of relay can be counted to the proportional length of the core

$$l_к \approx a_3 l_c. \qquad (4\text{-}119a)$$

After substituting into equation (6-8) instead of D_0 h and $l_к$ their values from (4-119) and (4-119a), we will obtain for the weight of copper of the winding:

$$Q_м = 8,9 \cdot 10^{-3} \pi a_2 a_3 k_3 l_c d_c (a_1 d_c + a_2 d_c) = 0,028 k_3 a_4 l_c d_c^2,$$

where

$$a_4 = a_2 a_3 (a_1 + a_2).$$

Consequently, gross weight of relay in grams can be expressed by the following formula:

$$Q \approx k_2 [12,25 \cdot 10^{-3} k_4 (1 + k_5) l_c d_c^2 + 0,028 a_4 k_3 l_c d_c^2] = \\ = 12,25 \cdot 10^{-3} k_2 [k_4 (1 + k_5) + 2,29 a_4 k_3] l_c d_c^2 \approx a_7 d_c^3. \quad (4\text{-}120)$$

For valve type miniature/small relay by weight approximately from 20 to 300 g, shielded by jackets, the value of coefficient k_2 varies within limits from 1.6 to 2. For the relay, which do not have jackets, k_2 = 1.2-1.6.

The value of coefficient k_4 for a similar relay is found approximately within limits from 0.9 to 1.6, and the value of coefficient k_5 varies usually from 0.2 to 0.5.

The advantageous value of coefficient a_2 in the case when the attracting force of the armature of relay is proportional $\sqrt{d_c^3}$, is equal to 0.72-0.8. However, virtually value a_2 is selected within limits from 0.7 to 1.0, since with a_2 = 0.72 diameter of the wire of the winding of miniature/small relays is obtained by very small and value k_3 considerably decreases.

Coefficients a_1 and a_3 have approximately the following values: a_1 = 1.05-1.15 and a_3 = 0.8-0.9.

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If we accept: k_2 = 1.8; k_2 = 0.5; k_4 = 1.3; k_5 =

0.35; a_1 = 1.1; a_2 = 0.7 and a_3 = 0.83, then a_4 = 1.045 and approximate values of gross weight of valve type relay, shielded jacket, will be equal to:

$$Q \approx 12{,}25 \cdot 10^{-3} l_c d_c^2 1{,}8\,[1{,}3\,(1+0{,}35) + 2{,}29 \cdot 1{,}045 \cdot 0{,}5] = \\ = (0{,}0387 + 0{,}0263)\, l_c d_c^2 = 0{,}065 l_c d_c^2. \quad (4\text{-}120a)$$

Thus, the weight of relay tentatively can be considered proportional to weight they began core.

Diameter and the length of the core of relay depend on the peak load of armature, amount of working clearance and power, necessary for the function of relay. With an increase in the power, consumed by relay during function, decreases the diameter and the length of core.

However, during the size decrease of core, decreases the cooling surface of winding and grow/rises its temperature. Therefore a decrease in the overall dimensions of the magnetic circuit of relay with the assigned load of armature is limited to the greatest temperature, permissible for the wire insulation of winding during prolonged operation.

Temperature excess of the winding of the relay, shielded by jacket, above the temperature of surrounding

air, is expressed by the approximation formula (9-53b):

$$\vartheta \approx \frac{200 \cdot P_m}{\sqrt[3]{S_{\text{н}}^2}} = \frac{200 \cdot P_c K_1^2 k_\Theta}{\sqrt[3]{S_{\text{н}}^2}},$$

where P_m - the power, scattered by winding, in W, $S_{\text{н}}$ - the calculated cooling surface of the winding of relay in cm², P_c - power of the function of relay, K_1 - a safety factor on current or actuation voltage at the moment of the connection/inclusion of relay, k_Θ - the coefficient, which considers a change in the required power as a result of an increase in winding impedance of relay during its heating. The value of coefficient k_Θ can be determined from formula (9-13). For current relay

$$k_\Theta = 1 + \alpha(\Theta - \Theta_0) = 1 + \frac{\vartheta}{234{,}5 + \Theta_0} = \frac{234{,}5 + \Theta_0 + \vartheta}{234{,}5 + \Theta_0} = \frac{254{,}5 + \vartheta}{254{,}5},$$

while for voltage relay

$$k_\Theta = \frac{234{,}5 + \Theta_0}{234{,}5 + \Theta_0 + \vartheta} = \frac{254{,}5}{254{,}5 + \vartheta},$$

where Θ_0 is the temperature of surrounding air whose value we take equal to 20°C.

if the calculated cooling surface of the winding of relay is given in mm², then formula (9-53b) takes the following form:

$$\vartheta \approx \frac{4520 P_c K_1^2 k_\Theta}{\sqrt[3]{S_{\text{н}}^2}}.$$

The calculated cooling surface of the winding of relay (without taking into account of faces of coil), is equal to:

$$S_{\kappa} = \pi\,[D_0 + (D_0 + 2h)]\,l_{\kappa}.$$

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Let us substitute into this equation for D_0, h and l_{κ} of their value from expressions (4-119) and (4-119a); then

$$S_{\kappa} = 2\pi a_3 (a_1 + a_2)\, l_c d_c,$$

where l_c is length of core in mm and d_c - the diameter of core in mm. Substituting in (9-53b) instead of S_{κ} its value from last/latter expression, we obtain:

$$\vartheta = \frac{4520 P_c K_1^2 k_\Theta}{\sqrt[3]{[2\pi a_3 (a_1 + a_2)\, l_c d_c]^2}},$$

whence we find formula for determining the smallest length of the core of relay (in mm) depending on the temperature of the overheating of winding and power of the function:

$$l_c \approx \sqrt{\frac{(4520 P_c K_1^2 k_\Theta)^3}{\vartheta^3 4\pi^2 a_3^2 (a_1 + a_2)^2 d_c^2}} = \frac{Z}{d_c}\sqrt{\frac{P_c^3}{\vartheta^3}}\ [\text{мм}], \quad (4\text{-}121)$$

where

$$Z = \frac{\sqrt{(4520 K_1^2 k_\theta)^3}}{2\pi a_3 (a_1 + a_2)}.$$

For miniature/small voltage relay, if we accept the safety factor on the actuation voltage equal to $K_1 = 2$ at the moment of connection/inclusion and the remaining coefficients $a_1 = 1.1$, $a_2 = 0.7$ and $a_3 = 0.83$, then

$$I_c \approx \sqrt{\frac{(4520 \cdot 2^2 \cdot 254{,}5 \cdot P_c)^3}{\theta^3 (254{,}5+\theta)^3 \cdot 4\pi^2 \cdot 0{,}83^2 \cdot (1{,}1+0{,}7)^2 \cdot d_c^2}} = \frac{2{,}59 \cdot 10^6}{d_c} \sqrt{\left[\frac{254{,}5 \cdot P_c}{(254{,}5+\theta)\,\theta}\right]^3}. \quad (4\text{-}121a)$$

For miniature/small current relay, the safety factor on spill current K_1 is necessary to take less than two to avoid the large overheating of winding.

At the temperature of the overheating of winding θ = 70°C power, consumed by voltage relay at the moment of connection/inclusion with $K_1 = 2$, is equal to the power, consumed by current relay with $K_1 = 1.57$.

Taking value $K_1 = 1.57$, we obtain for current relay:

$$l_c' \approx \sqrt{\frac{[4520 \cdot 1{,}57^2 \cdot (254{,}5+\vartheta) P_c]^3}{254{,}5^3 \cdot \vartheta^3 \cdot 4\pi^2 \cdot 0{,}83^2 \cdot (1{,}1+0{,}7)^2 d_c^2}} = \frac{1{,}25 \cdot 10^6}{d_c} \sqrt{\left[\frac{(254{,}5+\vartheta) P_c}{254{,}5 \cdot \vartheta}\right]^3}. \qquad (4\text{-}121b)$$

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If the greatest permissible temperature of the overheating of winding is equal to 70°C, then the smallest length of the core of voltage relay with $K_1 = 2$ at the moment of connection/inclusion and current relay with $K'_1 = 1.57$ will be identical and are equal to:

$$l_c \approx \frac{307}{d_c} \sqrt{P_c^3} \cdot [мм]. \qquad (4\text{-}121c)$$

The power, consumed by the winding of relay during function, is expressed by formula (1-1):

$$P_c = C \cdot AW_c^2,$$

where C - the averaged resistor/resistance of one turn of winding in ohms and AW_c - ampere-turns of the function of relay.

The value of the averaged resistor/resistance of one turn of winding according to formula (6-13) is equal to:

$$C = \frac{\pi\rho\,(D_0 + h)\cdot 10^{-3}}{l_{\kappa} h k_3},$$

where D_0 - an inner diameter of the winding of relay in mm, h - a height/altitude of winding in mm, l_{κ} - length of winding in mm, ρ - the resistivity of the material of wire in $\Omega\bullet mm^2/m$ and k_3 - a duty factor of winding space.

Let us substitute into equation (6-13) instead of D_0, h and l_{κ} their value from expressions (4-119) and (4-119a); we will obtain:

$$C = \frac{\pi\rho\,(a_1 d_c + a_2 d_c)\cdot 10^{-3}}{a_3 l_c a_2 d_c k_3} = \frac{\pi\rho\cdot 10^{-3}\,(a_1 + a_2)}{a_2 a_3 l_c k_3} = a_5 \frac{\pi\rho\cdot 10^{-3}}{l_c k_3}, \quad (6\text{-}13a)$$

where

$$a_5 = \frac{a_1 + a_2}{a_2 a_3}.$$

Valve type relays are manufactured in two modifications: with the core, equipped with the pole piece, and with core without the pole piece. Let us examine both cases.

a) Relays without the pole piece.

The ampere-turns of the function of valve type miniature/small relays, which have core as diameter

approximately from 3 to 18 mm and as length from 20 to 80 mm without the pole piece within the limits of a change in the working air gap from 0.3 to 1.2 mm, are expressed by the approximation formula (4-74):

$$AW_c \approx 50,9 \cdot \sqrt{\frac{F\sqrt{\sigma^3}\sqrt[3]{l}}{\sqrt{d_c^3}}},$$

where F - load of armature in grams and σ - the working clearance in mm, which corresponds to the critical point of the electromechanical characteristic of relay.

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Substituting in equation (1-1) instead of C and AW their values from expressions (6-13a) and (4-74), we obtain:

$$P_c \approx \frac{a_5\pi\rho\cdot 10^{-3}}{lk_3} 50,9^2 \frac{F\sqrt{\sigma^3}\sqrt[3]{l}}{\sqrt{d_c^3}} = \frac{0,1425a_5F\sqrt{\sigma^3}}{k_3\sqrt[3]{l^2}\sqrt{d_c^3}}. \quad (4\text{-}122)$$

After substituting into expression (4-121) instead of P_c its value from (4-122), we obtain:

$$l_c \approx \frac{Z}{d_c}\left(\frac{0,1425a_5F\sqrt{\sigma^3}}{\vartheta k_3\sqrt[3]{l_c^2}\sqrt{d_c^3}}\right)^{3/2} = \frac{Z}{d_c l_c d_c^{9/4}}\left(\frac{0,1425a_5F\sqrt{\sigma^3}}{k_3\vartheta}\right)^{3/2}.$$

Solving this equation relatively l_c, we find:

$$l_c \approx \frac{\sqrt{Z}}{d_c^{13/8}}\sqrt{\left(\frac{0,1425a_5F\sqrt{\sigma^3}}{k_3\vartheta}\right)^3}. \quad (4\text{-}123)$$

In expressions (4-121) and (4-122) enters the diameter

of the core of relay. The most advantageous value of the diameter of the core of relay at the assigned load of armature and this working air gap occurs in the case when the greatest magnetic induction in steel cf magnetic circuit is equal to 1.0-1.2 mT.

With an increase in the induction more than 1.0-1.2 mT, load characteristic of relay begins tc be bent, and sharply increase the magnetizing ampere-turns and the required power.

The smallest value of the diameter of the core of the relay, which does not have the pole piece, with the assigned load of armature F, working air gap σ and to the length of core l is expressed by the approximation formula (4-100):

$$d_c \approx 0{,}47\sqrt[4]{F}\sqrt[4]{\sigma l}.$$

Substituting in this equation for l its value from (4-123) and solving the obtained equation relatively d_c, we find formula for determining the throat diameter of the core of valve type relay, which does not have the pole piece, depending on the load of armature and temperature of the overheating of the winding:

$$d_c \approx 0{,}47 \left[\frac{Z}{0{,}47} \sqrt{\left(\frac{0{,}442 \cdot a_5}{k_3} \right)^3} \right]^{0{,}089} \frac{F^{0{,}37} \sigma^{0{,}378}}{\vartheta^{0{,}133}}. \qquad (4\text{-}124)$$

If we substitute into equation (4-123) instead of d_c its value from last/latter expression, then for the length of the core of relay we will obtain:

$$l_c \approx \left[\frac{Z}{0{,}47} \sqrt{\left(\frac{0{,}442 \cdot a_5}{k_3} \right)^3} \right]^{0{,}356} \frac{F^{0{,}1462} \sigma^{0{,}51}}{\vartheta^{0{,}535}}. \qquad (4\text{-}125)$$

The small value of the weight of relay, which does not have the pole piece, according to formula (4-120), will be equal to:

$$Q \approx 0{,}01225 k_2 [k_4 (1 + k_5) + 2{,}29 a_4 k_3] \left[\frac{Z}{0{,}47} \sqrt{\left(\frac{0{,}442 \cdot a_5}{k_3} \right)^3} \right]^{0{,}584} \times$$

$$\times \frac{F^{0{,}888} \sigma^{1{,}267}}{\vartheta^{0{,}802}}. \qquad (4\text{-}126)$$

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For miniature/small voltage relay, if we accept the values of coefficients equal to: $K_1 = 2$; $a_1 = 1.1$; $a_2 = 0.7$; $a_3 = 0.83$ and $\vartheta = 70°C$, then calculation formulas (4-123), (4-124), (4-125) and (4-126) they are simplified:

$$l_c \approx \frac{16}{d_c^{13/8}} \sqrt{(F\sqrt{\sigma^3})^3}, \qquad (4\text{-}123a)$$

$$d_c \approx \frac{3,61 F^{0,37}\sigma^{0,378}}{[\vartheta\,(254,5+\vartheta)]^{0,138}} = 0,94 F^{0,37}\sigma^{0,378}, \qquad (4\text{-}124a)$$

$$l_c \approx \frac{3505 F^{0,168}\cdot\sigma^{0,51}}{[\vartheta\,(254,5+\vartheta)]^{0,525}} \approx 16,3 F^{0,168}\sigma^{0,51} \qquad (4\text{-}125a)$$

and

$$Q \approx \frac{2980\cdot F^{0,838}\sigma^{1,267}}{[\vartheta\,(254,5+\vartheta)]^{0,663}} \approx 0,965 F^{0,838}\sigma^{1,267}. \qquad (4\text{-}126a)$$

These equations are valid also for current relay, if $K'_1 = 1.57$.

Substituting in (4-122) instead of d_c its value from expression (4-100), we obtain for the power of the function of relay another formula:

$$P_c \approx \frac{0,1425 a_3 F\sqrt{\sigma^3}}{k_3\sqrt[3]{F}\sqrt{(0,47\sqrt[3]{F}\sqrt[4]{\sigma}\,l)^3}} = \frac{0,442 a_3}{k_3}\cdot\frac{F^{0,5}\sigma^{1,125}}{l^{1,042}}. \qquad (4\text{-}122a)$$

The power, consumed during the function of the relay of minimum weight, is determined with the aid **of formula** (4-122) by means of substitution instead of l **and** d_0 **their** values from expressions (4-124) and (4-125).

In certain cases during calculation, is assigned also the power of the function of relay. If the amount of the assigned power proves to be less than the power, determined by formula (4-122), then the length of core it is necessary to increase against the minimum value, found from (4-125).

In this case for determining the length of core, one should use the formula (4-122a) from which we find:

$$l \approx \left(\frac{0,442 \cdot a_s F^{0,4} \sigma^{9/4}}{k_s P_c}\right)^{25/36} = \left(\frac{0,442 \cdot a_s}{k_s}\right)^{0,36} \frac{F^{0,44}\sigma^{1,08}}{P_c^{0,36}}, \qquad (4\text{-}127)$$

where P_c **- the assigned magnitude of the power of the** function of relay.

Substituting in (4-100) instead of l its value from **last/latter expression, we obtain:**

$$d_0 \approx 0,387 \left(\frac{a_s}{k_s}\right)^{0,36} \frac{F^{0,434}\sigma^{0,18}}{P_c^{1,482}}. \qquad (4\text{-}128)$$

The weight of relay in this case will be equal to:

$$Q_c \approx 0{,}84 \cdot 10^{-3} k_3 [k_4(1 + k_5) + 2{,}29 a_4 k_3] \left(\frac{a_5}{k_3}\right)^{1{,}448} \frac{F^{1{,}388} \sigma^{2{,}12}}{P_c^{1{,}442}}. \quad (4\text{-}129)$$

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For a miniature/small relay at the taken above values of the coefficients of formula (4-127), (4-128) and (4-129) they are simplified:

$$l_c \approx 2{,}63 \frac{F^{0{,}48} \sigma^{1{,}08}}{P_c^{0{,}96}}, \quad (4\text{-}127a)$$

$$d_c \approx 0{,}6 \frac{F^{0{,}634} \sigma^{0{,}33}}{P_c^{0{,}24}} \quad (4\text{-}128a)$$

and

$$Q \approx 0{,}0614 \frac{F^{1{,}388} \sigma^{2{,}12}}{P_c^{1{,}442}}. \quad (4\text{-}129a)$$

B) relays with the pole piece.

The ampere-turns of the function of valve type miniature/small relays, which have cores as diameter

approximately from 3 to 18 mm and as length from 20 to 80 mm with the pole piece within the limits of a change in the working clearance from 0.3 to 1.2-1.5 mm, are expressed by the approximation formula (4-75):

$$AW_c \approx 57{,}7 \sqrt{\frac{F\sqrt{\sigma^3}\sqrt[3]{l}}{\sqrt{d_п^3}}} = 57{,}7 \sqrt{\frac{F\sqrt{\sigma^3}\sqrt[3]{l}}{\sqrt{a_б^3 d_c^3}}},$$

where $d_п$ **- a diameter of the pole piece and** $a_б$ - ratio of the diameter of the pole piece to the diameter of core.

The advantageous relationship/ratio between the diameter of the pole piece and the diameter of ccre increases of proportionally to the value clearance and decreases with an increase of the magnetic core induction. Its value usually is within the limits from 1.5 to 2.

Let us substitute into expression (1-1) instead of C **and** AW_c **their** values from (6-13a) and (4-75); we will **obtain:**

$$P_c \approx \frac{0{,}183 \cdot a_б F\sqrt{\sigma^3}}{k_з \sqrt[3]{F}\sqrt{a_б^3 d_c^3}}. \qquad (4\text{-}130)$$

Substituting in equation (4-121) instead of P_c its value from (4-130), we obtain:

$$l_c \approx \frac{Z}{d_c}\left(\frac{0{,}183 a_б F\sqrt{\sigma^3}}{k_з \theta \sqrt[3]{F}\sqrt{a_б^3}\sqrt{d_c^3}}\right)^{2/3} = \frac{Z}{d_c d_c^{2/9}}\left(\frac{0{,}183 a_б F\sqrt{\sigma^3}}{k_з \theta \sqrt{a_б^3}}\right)^{2/3}.$$

Solving this equation relative to l, we find:

$$l_c \approx \frac{\sqrt{Z}}{d_c^{13/8}} \sqrt[4]{\left(\frac{0,183 a_5 F \sqrt{\sigma^6}}{k_3 \sqrt{a_5^3}\Theta}\right)^3}. \qquad (4\text{-}131)$$

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The smallest value of the diameter of the core of relay with the pole piece at the assigned load of armature F, working air gap σ and the length of core l, is expressed by formula (4-102):

$$d_c \approx 0,71 \sqrt[3]{F\sqrt{\sigma l}}.$$

Substituting in this expression for l its value from (4-131) and solving the obtained equation relatively d_c, we find the formula for determining the throat diameter of the core of valve type relay, which has the pole piece:

$$d_{cm} \approx 0,71 \left[\frac{Z}{0,71} \sqrt{\left(\frac{0,306 a_5}{k_3 \sqrt{a_6^5}}\right)^3}\right]^{0,065} \frac{F^{0.26}\sigma^{0.279}}{\Theta^{0.0983}}. \qquad (4\text{-}132)$$

If we substitute into equation (4-131) instead of d_c its value from last/latter expression, then we will obtain for the length of the core of the relay:

$$l_c \approx \left[\frac{Z}{0,71} \sqrt{\left(\frac{0,306 a_5}{k_3 \sqrt{a_6^5}}\right)^3}\right]^{0,393} \frac{F^{0.164}\sigma^{0.672}}{\Theta^{0.59}}. \qquad (4\text{-}133)$$

The small value of the weight of valve type relay,

which has the pole piece, according to formula (4-120), will be equal to:

$$Q_{м}\approx 6,17\cdot 10^{-8}k_{3}\,[k_{4}(1+k_{5})+2,29a_{4}k_{3}]\left[\frac{Z}{0,71}\sqrt{\left(\frac{0,306a_{5}}{k_{3}\sqrt{a_{6}^{3}}}\right)^{3}}\right]^{0,524}\times$$
$$\times\frac{F^{0.884}\sigma^{1.23}}{\vartheta^{0.787}}.\quad (4\text{-}134)$$

For miniature/small voltage relay, if we accept the values of coefficients equal to: $K_1 = 2$; $a_1 = 1.1$; $a_2 = 0.7$; $a_3 = 0.83$; $a_6 = 1.6$; $\vartheta = 70°C$, then calculation formulas (4-131), (4-132), (4-133) and (4-134) they are simplified:

$$l_{c}\approx\frac{11,4}{d_{c}^{15/8}}\sqrt[4]{(F\sqrt{\sigma^{3}})^{3}},\quad (4\text{-}131a)$$

$$d_{c}\approx 2,79\frac{F^{0.36}\sigma^{0.270}}{[\vartheta\,(254,5+\vartheta)]^{0.0083}}=1,035F^{0,36}\sigma^{0,270},\quad (4\text{-}132a)$$

$$l_{c}\approx\frac{3700F^{0.164}\sigma^{0.672}}{[\vartheta\,(254,5+\vartheta)]^{0.50}}=9,95F^{0,164}\sigma^{0,672}\quad (4\text{-}133a)$$

and

$$Q_{м}\approx 1855\frac{F^{0.884}\sigma^{1.23}}{[\vartheta\,(254,5+\vartheta)]^{0.787}}=0,675F^{0,884}\sigma^{1,23}.\quad (4\text{-}134a)$$

These equations are valid also for current relay, if $K'_1 = 1.57$.

Substituting in (4-130) instead of d_c its value from formula (4-102), we obtain for the power of the function of relay another formula:

$$P_{c}\approx\frac{0,183a_{5}F\sqrt{\sigma^{3}}}{k_{3}\sqrt[3]{l^{3}}\sqrt{a_{6}^{3}}\,(0,71\sqrt[3]{F\sqrt{\sigma l}})^{5/3}}=\frac{0,306a_{5}}{k_{3}\sqrt{a_{6}^{3}}}\cdot\frac{F^{0.6}\sigma^{1.05}}{l^{0.917}}.\quad (4\text{-}135)$$

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The power, consumed during the function of the relay of minimum weight, is determined usually with the aid of formula (4-130).

If is assigned also the power of function, but the amount of the power of function, determined with the aid of formula (4-130), will prove to be more than assigned, then the length of core it is necessary to increase.

In this case for determining the length of the core it is necessary to use the formula (4-135) from which we find:

$$l_c \approx \left(\frac{0{,}306 a_5 F^{0.5} \sigma^{1.25}}{k_3 \sqrt{a_5^3} P_c}\right)^{12/11} = \left(\frac{0{,}306 a_5}{k_3 \sqrt{a_5^3}}\right)^{1{,}09} \frac{F^{0.545} \sigma^{1.362}}{P_c^{1{,}09}}. \quad (4\text{-}136)$$

Substituting in equation (4-102) instead of l its value of last/latter expression, we will obtain:

$$d_c \approx 0{,}565 \left(\frac{a_5}{k_3 \sqrt{a_1^3}}\right)^{0{,}182} \frac{F^{0.424} \sigma^{0.394}}{P_c^{0{,}182}}. \quad (4\text{-}137)$$

In this case the weight of relay will be:

$$Q \approx 1{,}08 \cdot 10^{-3} k_3 [k_4 (1 + k_5) + 2{,}29 a_4 k_3] \left(\frac{a_5}{k_3 \sqrt{a_5^3}}\right)^{1{,}654} \frac{F^{1.392} \sigma^{2.15}}{P_c^{1{,}654}}. \quad (4\text{-}138)$$

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CALCULATION OF ELECTROMAGNETIC RELAYS FOR EQUIPMENT FOR AUTOMAT--ETC(U)
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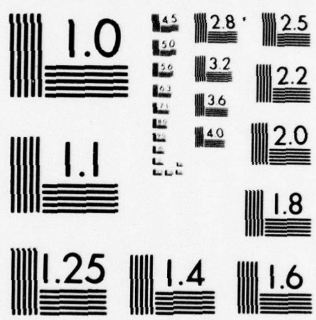

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For a miniature/small relay at the assigned above values of the coefficients of formula (4-136), (4-137) and (4-138) they are simplified:

$$l_c \approx 0{,}935 \frac{F^{\text{[illegible]}}\delta^{\text{[illegible]}}}{P_c^{1{,}30}}, \qquad (4\text{-}136a)$$

$$d_c \approx 0{,}693 \frac{F^{\text{[illegible]}}\delta^{\text{[illegible]}}}{P_c^{0{,}182}} \qquad (4\text{-}137a)$$

and

$$Q \approx 0{,}0292 \frac{F^{\text{[illegible]}}\delta^{\text{[illegible]}}}{P_c^{1{,}454}}. \qquad (4\text{-}138a)$$

If load and the adjustment of relay do not change, then for the dependences of the diameter of core and weight of relay on the power of function we find from equations (4-137) and (4-138) the following expressions:

$$d_c \approx \frac{A_1}{P_c^{0{,}182}} \qquad (4\text{-}137b)$$

and

$$Q \approx \frac{A_2}{P_c^{1{,}454}} \approx \frac{A_2}{\sqrt{P_c^3}}, \qquad (4\text{-}138b)$$

where A_1 and A_2 - constant coefficients.

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In the case when the length of core does not change,

then with a constant value of load and adjustments of relay for changing the diameter of the pole piece within small limits we obtain from equation (4-130) the following expression:

$$d_{п} \approx \sqrt[3]{\left(\frac{0,183 a_3 F \sqrt{\sigma^3}}{k_3 \sqrt[3]{l^3} P_c}\right)^2} = \frac{A_3}{\sqrt[3]{P_c^2}}, \qquad (4\text{-}130a)$$

where A_3 - constant coefficient.

For relay of the type RES10, the diameter of core is equal to 3 mm, weight 6.5 g the value of coefficients A_1 = 2.41 and A_2 = 1.12.

For relay of the type RDCG, the power of function is equal to 0.0132 W, the diameter of the pole piece 8 mm the value of coefficient A_3 = 0.446.

Figures 4-50 gives the curves of the dependences of the diameter of core and tentative weight of relay, similar relays of the type RES10, on the power of function.

To whole those who were given above relationships are derived on the basis of the empirical formulas, obtained by author with the aid of the experimental characteristics of valve type miniature/small relays, which have cores as

diameter from 3 to 18 mm and as length from 20 to 80 mm. These relationship/ratios one should use for the calculation of valve type miniature/small relays, which have the size/dimensions of core, which are placed within limits indicated above.

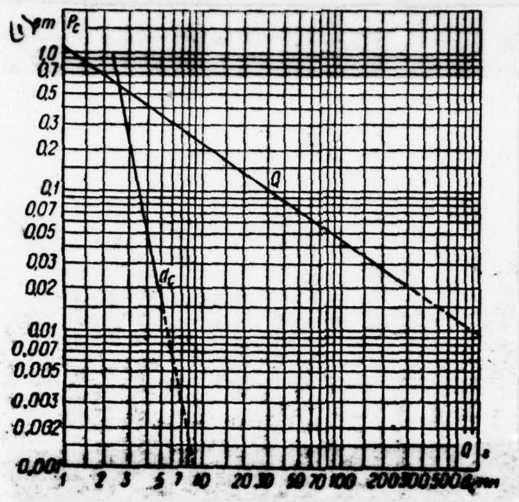

Fig. 4-50. **Curved of dependences of** diameter of core and tentative weight of relay, similar relays of type RES10 on power of function.

Key: (1). W.

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However, with some assumptions these formulas can be also used for tentative calculations of the miniature relays, which have the diameter of core of less 3 mm and the length of less 20 mm. In this case, it is necessary to consider that of miniature relay, especially in

pressurized/sealed performance, the ratio of the weight of relay to the weight of active materials (coefficient k_2) is more than in the miniature/small relay, shielded by jackets, and the value of this sense can oscillate over wide limits.

Values coefficient k_3, k_4, k_5, a_1, a_2, a_3 and a_4 of miniature relay also can change within large limits.

Therefore errors during the calculation of miniature relays are considerably more than with calculation of miniature/small relays by weight from 20 to 300 g.

Greatest divergences usually occur during the determination of the weight of miniature relays as a result of the large fluctuations of the value of coefficient k_2.

C) relays with the pulled armature.

The ampere-turns of the function of the relay with the pulled armature, which has air-gap diameter from 6 to 125 mm, are expressed by the approximation formula (4-77):

$$AW_c \sim 183\frac{\sqrt{F\sqrt{\delta^3}}}{d_n},$$

where F - load of armature in grams and σ - working clearance into mm, which correspond to the critical point of the electromechanical characteristic of relay.

Substituting in equation (1-1) instead of C and AW_c their values from expressions (6-13a) and (4-77), **we obtain:**

$$P_c \sim \frac{a_1 x\rho\cdot 10^{-8}}{l_c k_3}183^2\frac{F\sqrt{\sigma^3}}{d_n^2}=\frac{1,84 a_1 F\sqrt{\sigma^3}}{l_c k_3 d_n^2}. \quad (4\text{-}139)$$

Let us substitute into expression (4-121) **instead of P_c** its value from (4-139); we obtain:

$$l_c \sim \frac{Z}{d_n}\sqrt[3]{\left(\frac{1,84 a_1 F\sqrt{\sigma^3}}{l_c k_3 d_n^2}\right)^2}.$$

Solving this equation relatively l_c, **we** obtain formula for determining the smallest length **of coil** (core and armature) during continuous duty:

$$l_c \sim \left[\frac{Z}{d_n^{4}}\left(\frac{1,84 a_1 F\sqrt{\sigma^3}}{k_3\vartheta}\right)^{2/3}\right]^{3/5} = \frac{Z^{0,6}}{d_n^{2,4}}\left(\frac{1,84 a_1 F\sqrt{\sigma^3}}{k_3\vartheta}\right)^{0,4}. \quad (4\text{-}140)$$

For voltage relay, if we accept the values of coefficients equal to: K_1 = 1.35; a_1 = 1.1; a_2 = 0.5; a_3 = 1.0 and ϑ = 70°C, then

$$Z \sim \frac{1}{2\pi(1,1+0,5)}\sqrt[3]{\left(\frac{6520\cdot 1,35^2\cdot 234,5}{234,5+70}\right)^2} = 5,16\cdot 10^4,$$

and the smallest length of the winding of relay will be:

$$l_c \approx \frac{76{,}8}{d_я^{1,6}} \left(\frac{1{,}84 \cdot 3{,}2 F \sqrt{\sigma^3}}{k_з \vartheta} \right)^{0,6} = \frac{6}{d_я^{1,6}} \left(\frac{5{,}9 F \sqrt{\sigma^3}}{k_з} \right)^{0,6}. \quad (4\text{-}140a)$$

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These formulas are tentative and are used for the relay, which have air-gap diameter from 6 to 125 mm, the ratio of the length of coil to air-gap diameter approximately from 2.1 to 2.7 (3.8) at the appropriate values of the quantity of working air gap (course of armature), that are located between curves, given in Fig. 4-36.

For facilitation and simplification in the computations in appendix 3, are given dependence curves of values y^x from the value of base y at the different values of exponent x within limits of the values of base y from 1 to 100 and x from 0.1 to 1.5 (6.0).

For determining the values y^x with values y, it is less than 1 and more than 100 one should present these values in the form of fraction or products, for example:

$$0{,}065^x = \frac{6{,}5^x}{100^x} \quad \text{or} \quad 650^x = 6{,}5^x \cdot 100^x.$$

4-14. Specific consumption of materials and the weight of relay.

During the design of the magnetic systems of electromagnets and relay, it is necessary to most rationally utilize materials. The correctly designed electromagnet has smallest weight and overall size per unit of useful work.

The ratio of the weight of electromagnet to the greatest value of its conditional operation at the maximum temperature of the overheating of winding is called specific expenditure of materials whose value characterizes the cost-effectiveness/efficiency (quality) of the construction:

$$D = \frac{Q}{A_1}. \qquad (4\text{-}141)$$

For each form (of type) of the magnetic system of electromagnet are optimum relationship/ratios between the attracting force and the course of the armature by which the weight of electromagnet reaches minimum value.

Experiment shows that larger thrust have the electromagnets with the high diameter of core.

The advantageous value of induction for this type of electromagnet can be considered a constant value within some limits; therefore from equation (4-63a) it follows that the diameter of core is proportional to square root of attracting force:

$$d = \frac{1,78 \cdot 10^4 \sqrt{F}}{B} = a\sqrt{F}.$$

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The length of core depends on the magnetizing ampere-turns of the windings which are proportional to the value of the course of armature. Therefore the ratio of square root of attracting force to value course of armature characterizes the form (type) of electromagnet and does not depend on its size/dimensions. This sense is called structural index or the structural/design factor of the electromagnet:

$$\Pi = \frac{\sqrt{F}}{\delta}. \qquad (4\text{-}142)$$

It is experimentally establish/installed that for each form (of type) of electromagnet the small value of the specific consumption of materials is included within some specific limits value of structural index.

The absolute value of the value of the specific consumption of materials variably depends also on the size/dimensions of electromagnet [4-22].

Experiment shows that for each form (of type) of electromagnet the minimum value of the specific consumption of materials occurs with some specific limits of the value of structural/design factor.

For valve type, electromagnets the smallest value of the specific consumption of materials occurs during a change of the structural/design factor within limits from 2.6 to 26, for solenoid type electromagnets with conical stop - from 1 to 20, for solenoid type electromagnets (direct system) with flat/plane stop - from 16 to 90, for two-coil beam relay armature - from 6 to 200 and for solenoid long-stroke electromagnets (without stop) the value of structural/design factor less than 0.2.

The dependence of the greatest conditional work on the weight of relay and temperature of the overheating of winding can be obtained, if we disregard the saturation of

magnetic circuit and the effect of leakage fluxes.

Let us substitute into equation (4-92a) instead of P and R_δ their values from expressions (9-54) and (4-28); let us assume that d_n and δ are proportional to d and will replace d by its value from expression (4-120); we will obtain:

$$A_{1m} = a_8\vartheta \sqrt{Q}\left(\sqrt[3]{\frac{Q}{a_7}}\right)^2 = a_9\vartheta Q^{7/6} = a_9\vartheta Q^{1,17}. \qquad (4\text{-}143)$$

Figures 4-51 gives the curves of the dependences of conditional work on the weight of valve type relay at the different values of the temperature of the overheating of the windings, constructed by author on the basis of experimental materials. The deviation of these curves from straight lines at the low values of weight is explained by the relatively larger course of armature, establish/installed of the specimen/samples of relay No 2, 3 and 4.

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Within the limits of the weight of relay from 5 to 2300 G, the indicated curves are virtually straight lines and they can be approximated by the following approximation formulas:

at ϑ = 70°C

$$A_{70} = 0,55Q^{0,96} \approx 0,41Q, \qquad (4\text{-}144a)$$

at ϑ = 50°C

$$A_{50} = 0,41Q^{0,96} \approx 0,38Q. \qquad (4\text{-}144б)$$

Figures 4-52 gives the curves of the dependences of the specific consumption of materials on the weight of valve type relay (without jacket) with the overheating of winding into 30 and 70°C, constructed with the aid of the curves of Fig. 4-51.

From the curves of Fig. 4-52, it follows that with the overheating of winding in 70°C and weight from 4 to 30 g the specific consumption of materials varies from 1.9 to 2.1 g to one gram- centimeter of conditional work.

With a further gain in weight of relay to 2300 g, the specific consumption of materials increases to 2.9 g/G•cm.

A considerable increase in the specific consumption of materials during reduction in the weight of relay from 4 to 1.8 g is explained by the relatively larger course of armature of a small relay.

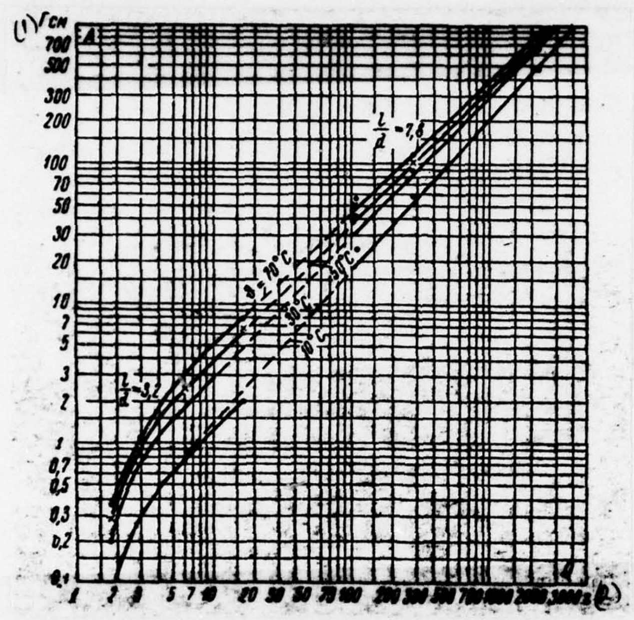

Fig. 4-51. Curved of dependences of conditional work on weight of valve type relay at different values of temperature of heating of winding.

Key: (1). Fuel and lubricants. (2). g.

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With the overheating of winding in 30°C and the weight of relay from 4 to 2300 g, the specific consumption of materials does not virtually vary and composes approximately

3.5 g/G•cm.

Miniature/small sealed relays have the specific consumption of materials 2.5-3.5 g/G•cm with ϑ = 70°C.

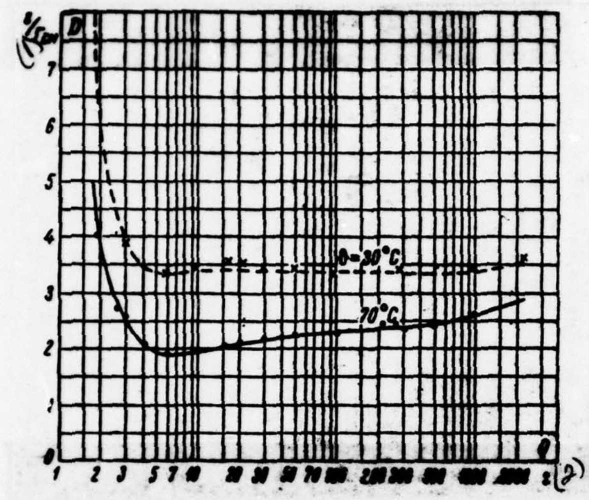

Fig. 4-52. Curved of dependences of specific consumption of materials on weight of valve type relay (without jacket) at different temperatures of overheating of winding.

Key: (1). g/Ω•cm. (2). g.

4-15. Resetting ratio.

The ratio of the ampere-turns of release/tempering to the ampere-turns of function is called the relay reset coefficient:

$$k_{в} = \frac{AW_{от}}{AW_{ср}}. \qquad (4\text{-}145)$$

Resetting ratio has great value during the coincidence of mechanical and electromechanical characteristics of relay. For an increase in the relay reset coefficient with external hinged armature, it is necessary to increase the height/altitude (thickness) of the plug of loosening and to decrease the course of armature.

Figures 4-53 gives tentative the curves of the dependences of the resetting ratio of the different types of relay on the height/altitude of the plug of loosening (remanent/residual nonmagnetic gap after the attraction of armature). Dotted lines plotted/applied the curves of the

dependences of the ampere-turns of function in the percentages of these relays on the height/altitude of the plug of loosening.

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The course of armature of relay of the type RDCG is equal to 0.1 mm, relay of the type RMU - 0.35 mm, relay of the type RKN - 0.8 mm and relay of the type REN17 -

1.7 mm.

A relay of the type REN17 is loaded by two changing over and by two circuit closing contacts, the relays of types RKN, RKM-1 and RMU - by two stud switches. A relay of the type RDCG has rigid contact system with one stud switch.

From curves, given in Fig. 4-53, it follows that with an increase in the permanent air gap of relay of the type RDCG from 0.1 to 0.4 mm the value of the resetting ratio of this relay grow/rises approximately from 0.39 to 0.74, and the ampere-turns of the function of relay in this case increase 2.27 times.

With increase in altitude of the plug of loosening from 0.1 to 0.5 mm and loads, indicated above the resetting ratio grow/rises at a normal relay of the type RKN from 0.12 to 0.59, of a test relay of the type RKN (diameter of pole 9 mm) from 0.3 to 0.67; of relay of type RKM-1 from 0.27 to 0.64, but of relay of the type REN17 from 0.18 (with δ_0 = 0.2 mm) to 0.39. The ampere-turns of the function of these types of relay with an increase δ_0 to 0.5 grow/rise, correspondingly, to 40, 60, 38 and 15o/o.

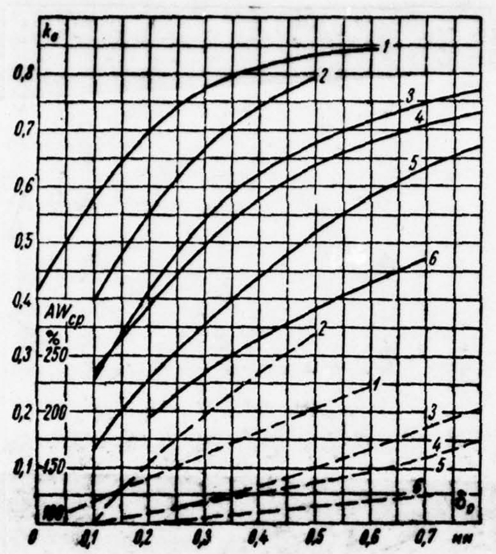

Fig. 4-53. Curved of dependences of resetting ratio and ampere-turns of function of relay on height/altitude of plug of loosening. 1 - type RMU; 2 - type RDCG; 3 - type RKN (test [illegible] mm); 4 - type RKMb-1; 5 - type of RKN normal; 6 - type REN17.

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The power, consumed by relay of the type REN17, is great; therefore the application/use of a plug of loosening by the height/altitude of more than 0.5 mm is impossible due to the overheating of winding. To considerably decrease

the course of armature of relay of this type for an increase k_B also is not represented possible due to the need of providing the ample clearance between contacts (it is not less than 0.9 mm) and a sufficient contact pressure (20-25 G) with flexible contact springs.

The greatest resetting ratio $k_B = 0{,}84$ has relay of the type RMU, with load by two stud switches and δ_0 = 0.5 mm.

The ampere-turns of the function of relay of the type RMU with δ_0 = 0.5 mm increase two times.

The relay reset coefficient depends also on the load of armature (number of contact springs and pressure in contacts). With an increase in the load of the relay of types RKN, RKM-1, REN17 and RMU the resetting ratio increases, but a highly sensitive relay of the type RDCG - on the contrary, it decreases.

It is necessary to note that the calculated (certified/rating) relay reset coefficient, which do not have continuously variable control of course, is always lower than real approximately to 40-60o/o, since the calculated

ampere-turns of function usually to 10-20o/o are greater than actual, but the calculated ampere-turns of release/tempering - to 30-50o/o are less than actual.

Polar relays of type RP-5 with the current of sensitivity have a resetting ratio $k_s = 0.95 \div 0.97$, but after an increase of the coil current up to the value, which corresponds 10 ab, value k_s decreases to 0.65-0.85. The relay reset coefficient of type RP-7 is equal to 0.2-0.5.

Maximum value resetting ratio reaches at magnitoelectric relay - to 0.99.

4-16. Calculation of the permanent magnets.

The calculation of the permanent magnets is conducted with the aid of demagnetization curves of the corresponding magnetically hard materials from which are made these magnets [4-39, 4-40].

Magnetic induction along the length of the permanent magnet is distributed unevenly, great value induction has in

the mean section of magnet.

For determining the magnetic induction $B_м$ in the mean section of magnet, it is necessary to construct in Fig. 4-54a straight line which is carried out at an angle γ to the axis of abscissas and it intersects demagnetization curve of the material of magnet.

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The tangent of angle γ is determined from the following formula:

$$tg\gamma = \frac{l_м G_в \sigma m_H}{S_м m_B}, \quad (4\text{-}146)$$

where $l_м$ - length of the permanent magnet, $S_м$ - a section of magnet, $G_в$ - permeance of working air gap, σ - a coefficient of scattering magnetic flux, m_H - scale of the voltage of field along the axis of abscissas and m_B - scale of induction along the axis of ordinates.

In this formula the coefficient of scattering the magnetic flux

$$\sigma = \frac{G_в + G_н + G_у}{G_в}, \quad (4\text{-}147)$$

where $G_к$ is conductivity of edge fluxes of magnet poles and $G_у$ - leakage conductance along the length of magnet. The value of coefficient of scattering σ in the various polarized magnetic systems varies within limits from 2 to 5 (10).

Magnetic flux in the mean section of magnet, obviously, is equal to:

$$\Phi = B_м S_м.$$

Working air-gap flux of magnet considering leakage flux it will be:

$$\Phi_\delta = \frac{B_м S_м}{\sigma}. \quad (4\text{-}148)$$

The average value of magnetic induction in working magnet gap

$$B_\delta = \frac{B_м S_м}{\sigma S_\delta}, \quad (4\text{-}149)$$

where S_δ is a section of working air gap.

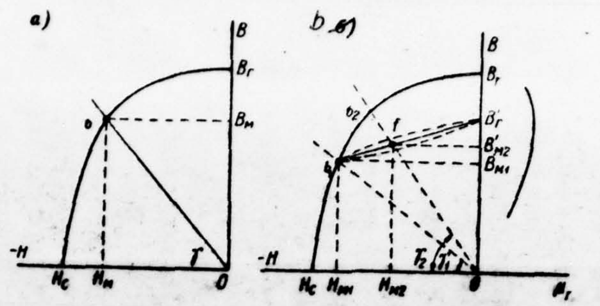

Fig. 4-54. **Determination by graphic plotting** of induction in mean section of permanent magnet.

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Magnetic intensity in working air magnet gap is equal to magnetic induction in this gap

$$H_B = B_B = \frac{H_M l_M}{k l_B} = \frac{H_M l_M}{1{,}35 l_B}, \qquad (4\text{-}150)$$

where H_M **is magnetizing force in magnet,** l_B - the length of working air gap and k - the coefficient, which considers a decrease (loss) in magnetizing force due to the presence of air gap.

The value of coefficient k varies within the limits approximately from 1.2 to 1.5 and can be accepted on the

average equal to 1.35.

From equations (4-149) and (4-150) we obtain for determining of section and length of the permanent magnet the following formulas:

$$S_{м} = \frac{B_{в} S_{в} \sigma}{B_{м}} \tag{4-151}$$

and

$$l_{м} = \frac{1{,}35 B_{в} l_{в}}{H_{м}}. \tag{4-152}$$

Magnetic energy of the permanent magnet, as is known, is equal to:

$$W = \frac{BH}{2} V, \tag{4-153}$$

where V is space of the permanent magnet.

The value of quantity B on demagnetization curve varies from zero to B_r, and the corresponding values H are from H_c, to zero. Consequently, the value of magnetic energy varies first from zero to maximum and then again it drops to zero.

For determining maximum energy of the permanent magnet, it is necessary through points B_r and H_c with Fig. 4-55 to conduct by dotted line in parallel to the axes

coordinates two straight lines and the point of their intersection to connect with the origin of coordinates by straight line.

The point b_d of the intersection of this straight line from demagnetization curve determines the optimum values of the strength of field H_d and of the magnetic induction B_d in the mean section of magnet, during which magnetic energy W has great value.

For obtaining the magnet of the minimal sizes of value B_m and H_m in formulas (4-151) and (4-152) must have values, the close to optimum: B_d and H_d.

The value of coefficient of scattering depends on size/dimensions and the form of magnet; therefore during precomputation it is necessary to be given tentative value σ and to conduct calculation by the method successive conducting of.

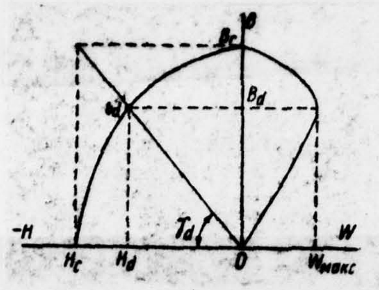

Fig. 4-55. Determination graphically of maximum energy of permanent magnet.

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In manual "permanent magnets" [4-39] is given curve/graph for determining the tentative value of coefficient of scattering for three simplest circuits of magnetic circuit.

Usually the permanent magnets are utilized in the magnetic circuit, which contains armature (pole pieces, armature so forth), prepared from mild transformer steel or ni-span alloys.

If in this case the permanent magnet is remove/taken

and is magnetized separately from armature (with the aid of magnetizing coil), then the value of magnetic induction B_{M1} in the mean section of magnet will be determined with the aid of the straight line Ob_1, carried out at an angle γ_1 in Fig. 4-54b.

The tangent of angle γ_1 for a magnet without the armature

$$\mathrm{tg}\,\gamma_1 = \frac{l_M G_{B1} \sigma_1 m_H}{S_M m_B}, \qquad (4\text{-}146a)$$

where G_{B1} is permeance of air magnet gap without armature and σ_1 - the coefficient of scattering magnet without armature.

After magnetization the magnet is collect/built together with armature, the real value of the air magnet gap decreases and its permeance increases, which corresponds to the straight line Ob_2, carried out at an angle γ_2.

The tangent of angle γ_2 for a magnet with the armature

$$\mathrm{tg}\,\gamma_2 = \frac{l_M G_{B2} \sigma_2 m_H}{S_M m_B}, \qquad (4\text{-}146б)$$

where G_{B2} is permeance of working air gap (with armature)

and σ_2 - the coefficient of scattering magnet with armature.

However, after the connection (assembly) of magnet with armature, an increase in the magnetic induction up to value B_{mg}, as a result of an increase in the conductivity of air gap, will occur not in demagnetization curve, but in another dotted curve, which differs little from the direct/straight $b_1 f B_r'$ and called curve of return.

Rate of change to the curve of return to the axis of abscissas, is called the reversible permeability μ_r. The value of induction in the mean section of magnet B_m is determined by the point of intersection f of the auxiliary straight line Ob_2 from the curve of return $b_1 f B_r'$.

The average value of magnetic induction in working air magnet gap with armature will be equal to:

$$B_{wg} = \frac{B_{mg} S_m}{\sigma_g S_{wg}}. \qquad (4\text{-}149a)$$

The material of magnet is selected taking into account the provision for the necessary value of magnetic induction in working gap.

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The calculation of magnet is conducted by the method successive conducting of, moreover the size/dimensions of magnet are selected in such a way that magnetic energy, given up by magnet, would have maximum value.

4-17. Examples.

1. Let us determine analytically ampere-turns of functicn of relay of the type RKN, if load at predicted critical point with σ = 0.7 mm is equal to 510 G (5 newton). Diameter of the pole piece 1.5 cm, thickness its 3 mm. Diameter of core 0.9 cm, length its 6.7 cm. Section of housing 0.82 cm². Distance c_1 = 2.1 cm and c = 1.3 cm.

permeance between core and armature according to formula (4-28)

$$G=\frac{2\pi\cdot 2{,}1\cdot 10^{-2}}{0{,}7\cdot 10^{-3}}\mu_0\left(2{,}1\cdot 10^{-2}-\sqrt{2{,}1^2\cdot 10^{-4}-0{,}75\cdot 10^{-4}}\right)=0{,}26\mu_0 \quad \text{Wb/A}].$$

Permeance of leakage paths according to formulas (4.29) and (4.30)

$$G_1 = 0{,}58\mu_0 (5{,}14 \cdot 0{,}75 \cdot 10^{-2} + 1{,}57 \cdot 0{,}7 \cdot 10^{-2}) = 0{,}02\mu_0\ [вб/а];^{(1)}$$
$$R_1 = (2{,}1 - 0{,}75) \cdot 10^{-2} = 1{,}35 \cdot 10^{-2}\ м;\quad R_2 = (2{,}1 + 0{,}75) \cdot 10^{-2} = 2{,}85 \cdot 10^{-2}\ м;$$
$$G_2 = 2{,}3 \cdot 10^{-2}\mu_0 \left(1 + \frac{4 \cdot 0{,}75 \cdot 10^{-2}}{3 \cdot 10^{-2} + 2 \cdot 0{,}7 \cdot 10^{-2}}\right) = 0{,}05\mu_0\ [вб/а].^{(1)}$$

Key: (1). Wb/A.

Common/general/total reluctance of the working air gap

$$R_\delta = \frac{1}{G_\delta'} = \frac{1}{(0{,}28 + 0{,}02 + 0{,}05)\mu_0} = \frac{3{,}03}{\mu_0}\ [A/Wb].$$

Thickness of the coatings of core and housing: copper 0.005 mm nickel 0.01 mm. Length of average air gap 0.045 mm. Area of the joint of housing with armature 1.5 cm².

The reluctance of the joint of housing with the armature

$$R_{ст} = \frac{(0{,}003 + 0{,}0045) \cdot 10^{-3}}{1{,}5 \cdot 10^{-4}\mu_0} = \frac{0{,}5}{\mu_0} \quad [A/Wb].$$

Complete reluctance of the clearance

$$R_з = \frac{3{,}03}{\mu_0} + \frac{0{,}5}{\mu_0} = \frac{3{,}53}{\mu_0} \quad [A/Wb].$$

Area of the joint of core with housing 0.5 cm². The reluctance of the joint of core with the housing

$$R_0=\frac{0{,}003\cdot 10^{-3}}{0{,}5\cdot 10^{-4}\mu_0}=\frac{0{,}6}{\mu_0}\qquad [A/Wb].$$

The specific conductivity of leakage fluxes according to formula (4-39)

$$g=\frac{2\pi\mu_0}{\ln\dfrac{1{,}3\cdot 10^{-3}+\sqrt{1{,}3^2\cdot 10^{-6}-0{,}45\cdot 10^{-6}}}{0{,}45\cdot 10^{-3}}}=3{,}6\mu_0\qquad [Wb/A\bullet m].$$

Section of the pole piece

$$S_n=\frac{\pi\cdot 1{,}5^2\cdot 10^{-4}}{4}=1{,}77\cdot 10^{-4}\ m^2.$$

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The value of magnetic flux in the clearance of relay we find from formula (4-66):

$$\Phi_t=\sqrt{2\cdot 4\pi\cdot 10^{-7}\cdot 5\cdot 1{,}77\cdot 10^{4}(1+100\cdot 5\cdot 0{,}7\cdot 10^{-3})}=5{,}48\cdot 10^{-6}\ Wb.$$

Coefficient of scattering the pole piece

$$k_s=\frac{G'_\delta}{G}=\frac{0{,}26+0{,}02+0{,}05}{0{,}26}=1{,}27.$$

Value of magnetic flux of the end/lead of the core

$$\Phi_l' = \Phi_l k_c = 5{,}48 \cdot 10^{-6} \cdot 1{,}27 = 6{,}96 \cdot 10^{-6} \quad \text{Wb.}$$

The calculated length of core according to formula (4-19)

$$l_2 = \frac{6{,}7 \cdot 10^{-2} \cdot 3{,}53\,(0{,}6 \cdot 3{,}6 \cdot 6{,}7 \cdot 10^{-2} + 2)}{2\,(3{,}53 + 0{,}6 + 3{,}53 \cdot 0{,}6 \cdot 6{,}7 \cdot 10^{-2})} = 5{,}47 \cdot 10^{-2}\ м \text{ and } l_1 = 1{,}23 \cdot 10^{-2}\ м.$$

The maximum value of flow and flow value of heel of relay we find with the aid of formulas (4-20a) and (4-21):

$$\Phi_m = 6{,}96 \cdot 10^{-6}\left(1 + \frac{3{,}53 \cdot 3{,}6 \cdot 5{,}47 \cdot 10^{-2}}{2}\right) = 9{,}38 \cdot 10^{-6}\ Wb.$$

$$\Phi_a = 6{,}96 \cdot 10^{-6}\,\frac{3{,}53 \cdot 3{,}6 \cdot 5{,}47 \cdot 10^{-2} + 2}{0{,}6 \cdot 3{,}6 \cdot 1{,}23 \cdot 10^{-2} + 2} = 6{,}96 \cdot 10^{-6} \cdot 1{,}33 = 9{,}27 \cdot 10^{-6}\ Wb.$$

Average value of flow in core according to formula (4-25)

$$\Phi_{cp} = \Phi_l'\left(1 + \frac{R_\mu g l}{3}\right) = 6{,}96 \cdot 10^{-6}\left(1 + \frac{3{,}53 \cdot 3{,}6 \cdot 6{,}7 \cdot 10^{-2}}{3}\right) = 8{,}95 \cdot 10^{-6}\ Wb.$$

Average values of induction and relative permeability in core and housing of the relay

$$B_c = \frac{8,95 \cdot 10^{-8}}{0,636 \cdot 10^{-4}} = 1,41 \quad \text{ml}; \quad \mu_c = 1700$$

$$B_н = \frac{8,95 \cdot 10^{-8}}{0,82 \cdot 10^{-4}} = 1,09 \quad \text{ml} \quad \mu_н = 3500.$$

Average reluctance of the unit of the length of the magnetic circuit

$$R_m = \frac{10^4}{1700 \cdot 0,636\mu_0} + \frac{10^4}{3500 \cdot 0,82\mu_0} = \frac{12,7}{\mu_0} \quad [\text{A/Wb} \bullet \text{m}].$$

Value of coefficient q according to formula (4-13a)

$$q = 1 + \frac{6,7^2 \cdot 10^{-4} \cdot 3,6 \cdot 12,7}{3} = 1,068.$$

Ampere-turns of the function of relay according to formula (5-1)

$$AW = \frac{2 \cdot 5,48 \cdot 10^{-8}\, [6,7 \cdot 10^{-2}\, (12,7 + 3,53 \cdot 0,6 \cdot 3,6) + 1,068 \cdot (3,53 + 0,6)]}{(0,6 \cdot 3,6 \cdot 6,7 \cdot 10^{-2} + 2)\, 4\pi \cdot 10^{-7}} = 235 \text{ ampere-turns}$$

Ampere-turns, necessary for conducting the magnetic flux through interpiece space

$$AW_\delta = \frac{5,48 \cdot 10^{-8} \cdot 3,53}{4\pi \cdot 10^{-7}} = 154 \text{ ampere-turns}.$$

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2. Let us determine tentative values of fundamental parameters of miniature voltage relay of valve type.

The full load of the armature of relay at the critical point of mechanical characteristic is equal to 30 G with σ = 0.3 mm.

The safety factor on the actuation voltage at the moment of the connection/inclusion of the winding of relay let us take as equal to K_1 = 2. Greatest temperature of the overheating of winding let us take θ = 70°C.

For simplification in the calculation of the value of coefficients a_1; a_2; a_3; a_5; a_6; k_3; k_4 and k_5 let us accept as the same as for a miniature/small relay during the derivation of calculation formulas. The value of coefficient k_2 let us accept equal to 2.2.

A) relays without the pole piece.

The throat diameter of core is determined with the aid of formula (4-124a):

$$d_c \approx 0{,}94F^{0.37}\sigma^{0.378} = 0{,}94 \cdot 30^{0.37} \cdot 0{,}3^{0.378} = 2{,}1 \text{ мм.}$$

The smallest length of the core of relay, according to formula (4-125a), will be equal to:

$$l_c \approx 16{,}3F^{0.148}\sigma^{0.511} = 16{,}3 \cdot 30^{0.148} \cdot 0{,}3^{0.511} = 14{,}5 \text{ мм.}$$

The power, consumed by relay during function, we find through formula (4-122):

$$P_c \approx \frac{0{,}1425a_3F\sqrt{\sigma^3}}{k_3\sqrt[5]{l^3}\sqrt{d_c^3}} = \frac{0{,}1425 \cdot 3{,}1 \cdot 30\sqrt{0{,}3^3}}{0{,}5\sqrt[5]{14{,}5^3}\sqrt{2{,}1^3}} = 0{,}243 \text{ W.}$$

The tentative weight of relay with $k_2 = 2.2$, according to formula (4-120), is equal to:

$$Q_c \approx 0{,}08l_cd_c^2 = 0{,}08 \cdot 14{,}5 \cdot 2{,}1^2 = 5{,}1 \text{ g.}$$

B) relays with the pole piece.

The throat diameter of core is determined with the aid of formula (4-132a):

$$d_c \approx 1{,}085 \cdot 30^{0.36} \cdot 0{,}3^{0.379} = 2{,}5 \text{ мм.}$$

The smallest length of the core of relay, according to

formula (4-133a), will be equal to:

$$l_c \approx 9,95 \cdot 30^{0.164} \cdot 0,3^{0.673} = 7,74 \text{ мм}.$$

The power, consumed during the function of relay, we find through formula (4-130):

$$P_c \approx \frac{0,183 a_c F \sqrt{\sigma^3}}{k_3 \sqrt[3]{l^5} \sqrt{a_c^4 d_c^8}} = \frac{0,183 \cdot 3,1 \cdot 30 \sqrt{0,3^3}}{0,5 \sqrt[3]{7,74^5} \sqrt{1,6^4 \cdot 2,5^8}} = 0,178 \text{ W}.$$

The tentative weight of relay is equal to:

$$Q \approx 0,08 \cdot 7,74 \cdot 2,5^2 = 3,9 \text{ g}.$$

Thus, relays with the pole piece has by 30o/o smaller weight and requires for function to 36o/o smaller power, than the relay, which does not have the pole piece.

If the power of the function of relay must not exceed 0.1 W, then the length of core one should determine by formula (4-136a); we have:

$$l_c \approx 0,935 \frac{F^{0.545}\sigma^{1.362}}{P_c^{1.09}} = 0,935 \frac{30^{0.545} \cdot 0,3^{1.362}}{0,1^{1.09}} = 14,2 \text{ мм}.$$

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The diameter of the core of relay in this case, according to formula (4-102), must be equal to:

$$d_c \approx 0,71 \sqrt[3]{F\sqrt{\sigma l}} = 0,71 \sqrt[3]{30\sqrt{0,3 \cdot 14,2}} = 2,81 \text{ мм}.$$

The tentative weight of relay in this case, obviously, will be:

$$Q \approx 0,08 \cdot 14,2 \cdot 2,81^2 = 8,9 \text{ g.}$$

Consequently, the supplementary requirement for a decrease in the power of function to 0.1 W is led to an increase of the overall dimensions and weights approximately two times.